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DIASTROPHISM AND THE FORMATIVE PROCESSES. IV

REJUVENATION OF THE CONTINENTS

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That extensive peneplanation and wide sea-transgression had already taken place as early as the Ordovician period will scarcely be questioned by those who have studied the relations of the Paleozoic to the Proterozoic and Archean terranes. That wide peneplanation and sea-transgression has taken place repeatedly since is equally attested by ample evidence. This is equivalent to saying that peneplanation has been accomplished in periods that are only a fraction of the whole stratigraphic eon. This in turn implies that unless there had been some form of rejuvenation of the continents they would have been submerged early in geological history and the course of subsequent events would have followed lines far different from those that are actually recorded. The relative rapidity of the process of planation, slow as it is, appears the more declared when we recall that the original reliefs in the earliest eras, the Archean and the Proterozoic, were at once more impressive, more complex, and more resistant than those of the later eras. On no continent perhaps was this difference more notable than on North America. And yet, notwithstanding the intricacy and strength of the early reliefs, about one-half of North America was not only well peneplaned as early as the Mid-Ordovician stage,

but it was already covered by a wide, shallow sea, and there is indirect evidence that the rest of the continent had been brought to a relatively low level. While as yet studies on the peneplanation of some of the continents are little more than reconnaissances, there is sufficient evidence from such partial observations to warrant the belief that great progress toward a base-level had been made on all continents as early as the Ordovician period.

To broaden the support of these conclusions, it may be noted that the evidence of peneplanation is not confined to beveling surfaces cutting across upturned beds, or even to these combined with the wide extension of epicontinental strata. There is evidence of much cogency, though indirect and inferential, in the relative scantiness of terrigenous silts in the beds laid down near the land. Had the surface near the submerged areas remained high, the terrigenous silts must have had a nature and abundance appropriate to the drainage of high ground and would thus have testified to the fact of elevation. But some of the formations that mark the maximum sea-transgressions show a singular lack of coarse and abundant terrigenous silts. There were limestones that were certainly laid down in shallow, agitated water and yet maintained a high degree of purity, even on close approach to lands that were then emergent. This seems quite clearly to imply a low land surface from which only limited wash was derived. This inference is quite in harmony with the nature of the case, for a peneplanation that was effective enough to reduce a large fraction of the continent to a plain upon which the sea could creep forth would almost inevitably have reduced the remainder to low relief.

There is no need to dwell at length upon the processes of planation further than to recall the conception that runs through this discussion, the central feature of which is the close adjustment of a group of co-ordinate processes to the sea-surface as the controlling agency. The processes above the sea-surface embrace all those that gradually lower the land to the level of the sea at which their efficiency ceases. The processes below the sea-level embrace all those that co-operate with these in staying the terrigenous silts at the sea-border and building them into shelves just beneath the sea-surface. The mature result is a continental terrace, formed of a

girdling sea-shelf continuous with the peneplain of the land, the joint product of base-leveling on the reliefs, wave-cutting at the edge of the land, and shelf-building under the edge of the sea. All these were automatically adjusted to one another and to the sea-surface.

The slow partial filling of the sea that ran hand in hand with this gradation lifted the water-level, aided its landward progress and made room for new depositions on the surface of the growing shelf. Given sufficient time without disturbance, the process would inevitably have reduced the whole summit of the continent to a plain and even have submerged it beneath the sea-surface. The ultimate result would have been the reduction of the entire continental surface to a single terrace-top covered by an unbroken shelf-sea.

We have already noted that such a degree of progress toward complete peneplanation and sea-transgression had been made by the Mid-Ordovician stage that complete submergence must inevitably have ensued before the close of Paleozoic history, if there had not intervened some form of continental rejuvenation.

It is clear, however, that the prolonged state of quiescence requisite for complete base-leveling and submergence never was realized. The continuity of the land is attested by the terrigenous deposits that at no time were completely absent. The continuity of land life, after its early introduction, is attested by its own record and by evolutionary evidences. This testimony to the continuity of the land and of the land life would be cogent evidence of the rejuvenation of the continents if it stood alone. But it is reinforced by the record of the deformations that interrupted the course of earth history and that are yet to be sketched but may here be anticipated.

But, if these are facts of history, they can scarcely stand alone. The fact of continental rejuvenation implies suitable conditions and modes of action in the body deformed. If it is really true that the continents have been rejuvenated instead of being replaced by protrusions somewhere else, there is in this an intimation of appropriate conditions in the continents themselves. Either the continental matter was lighter than the suboceanic matter, or the attitude of continents to the basins was such as to favor a renewal of the

protrusion of the continents, or else both of these combined their good offices, as is most probable. There do not seem to be other competent alternatives.

If the rejuvenation really occurred at intervals, as implied in the statements already made, while the denudation of the continents, the loading of the borders of the basins, the loss of heat, the internal changes and other assigned agencies of deformation have been continuous, there must apparently have been *some adequate means of accumulating the constantly growing stresses* until a stress-limit was reached and yielding followed. This power of accumulation must have been *adequate* to the deformative results that followed. This forces a consideration of internal conditions.

The critical question that now arises is this:

Is the earth essentially a plastic body or at most a visco-solid, as so long held, or is it essentially an elastico-rigid body? This seems to me nearly equivalent to the question: Is the earth essentially a fluidal or quasi-fluidal body, or is it essentially a crystalline body? No one questions that it is partly the one and partly the other, but which is it dominantly in its working habit? If the main mass of the interior is fluidal or quasi-fluidal, the whole may well be viscous or plastic in its body habit and yield indefinitely and continuously to stresses that tend to deform it. Continuous loading may, in this case, be followed by continuous subsidence; continuous unloading, by continuous uprising, if hydrostatic equilibrium had been disturbed. Not so with a typical crystalline mass. The crystalline structure has for one of its essential features the definite arrangement of the molecules of each crystal in determinate positions with reference to adjacent molecules. Any stress that tends to move them from these determinate positions is resisted by an elastic force. Up to the elastic limit a strain only results, not a shear. Deformation is thus specifically limited until the elastic yield-point is reached. Beyond this the mass may be sheared, granulated, or fractured.

When crystals are intimately interlocked, as they are in typical holocrystalline rocks, the joint mass partakes of the qualities of the interlocked integers. In such a firm inter ocking of elastico-rigid units, stress gives rise to strain, but not to continuous shear, up to the yield-point of the elastic mass or of some of its integers. Beyond

this—but in the main only beyond this—shear movement or fracture movement may take place. Stresses must thus accumulate to a certain value before appreciable movement will set in. In this lies a basis for periodic movement in distinction from continuous movement, for under growing stress there is practically no movement until the yield-point is reached, when distinct and relatively free movement follows until the stress is eased.

Notwithstanding the radical difference between the behavior of a plastic and of an elastic body respectively under constantly growing stress, there are two ways in which deformative movements in bodies of the elastic type may simulate in outward aspect those of the plastic type. In an elastic crystalline body, a more or less gradual movement may take place when the interlocking crystals are so constituted that the stresses brought to bear on the whole mass are concentrated upon certain points at which the crystals press with so much special intensity and inequality upon one another that the point of solution, fusion or fracture is reached for these minute parts under these exceptional and unequal stresses. These minute parts then yield, and the dissolved, fused or granulated material readjusts itself at neighboring points of less stress. This material may or may not resolidify. By this yielding, similar intensified stresses are thrown upon other points which yield in turn. Thus a succession of yieldings of minute points is brought into play while the main mass remains more or less massively solid. It is a combination of two modes of movement—liquid, plastic, or granular movement at minute points, and massive movement for the rest. There is crystalline loss and usually a crystalline gain by transfer. The action is thus usually motion and metamorphism combined. The action is partial and distributive, in detail, and the *tout ensemble* very closely simulates a plastic movement—which indeed it is in part, but not as a whole. It is commonly interpreted as plastic, though it is not simply such. The best type is glacial motion.[1] When the temperature of a glacier is 0° C. and it is thus on the very border of liquidity, and when it is bathed in water on the very border

[1] "A Contribution to the Theory of Glacial Motion," *Decennial Publications of the University of Chicago*, 1904, pp. 193–204. See also Chamberlin and Salisbury, *Geology* I (1904), 294–306.

of solidity, as it is when melting is in progress, the change from ice to water and water to ice takes place with the utmost ease and is greatly facilitated by slight differences of stress. Glacial motion may then be almost as continuous and free from appreciable strains, ruptures and starts as the motion of a viscous body. But when the temperature is much lower and pervades the whole mass, its texture, and behavior are more rocklike, and strains, ruptures, starts, and microseismic phenomena are more pronounced. The mass is of course a crystalline rock of singular purity and the phenomena of strain, rupture, and start imminent in all cases under sufficient differential stresses. Crystalline orientation prevails at all stages.

The second case is found when the pressure on all sides is so intense that no separation of particles is possible and hence *continuity of contact* is forced, whatever may be the nature of the deformation that arises from the *differential* portion of the pressure, *which alone can give a typical deformative movement.* Such a deformation may take on the *aspect* of plastic deformation even though the minute process be one of granulation, or of progressive recrystallization, or otherwise.

These modes of pseudo-plastic movement, or, at most, partially plastic movement, qualify the distinctness between deformative movements normal to viscous or plastic bodies, on the one hand, and to rigid elastic bodies, on the other, without destroying the radical differences in their fundamental natures. The similarities in external aspect are of course a source of difficulty in interpretation. It is none the less necessary to take account of the distinctiveness of the opposed qualities. The nature of viscous or plastic bodies is favorable to continuous deformative movements so long as unequal stresses continue to arise. The nature of elastico-rigid bodies requires the delay of deformative movements until the inequalities of stress have reached the elastic limit of the aggregate or of its most stressed points. This difference gives the key to the interpretation of terrestrial deformations. It is in this difference that the phenomena of base-leveling, shelf-building, and sea-transgression, of the types we have set forth, find their elucidation. They seem to imply a crystalline elastic-rigid constitution of the earth-body.

There are of course other methods of determining the nature of the earth-body, such as the modes of the seismic vibrations that traverse the earth, the time-relations of the body-tides to the passing of the tide-producing bodies, and so forth. The testimony of these is indispensable to a full consideration of the nature of the earth-body, but we are here considering merely the bearing of the strictly geological arguments that spring from gradational phenomena.

As previously urged, a base-level of wide prevalence is practically impossible if diastrophic movements are in continuous progress, for warping and dislocation are inherently inimical to mature planation. So too in shelf-building, the range within which wave action is effective in distributing sediments, and the depth within which light is effective in photo-synthesis, are so narrow compared with the ranges through which warping and dislocation shift the crust that relatively little diastrophism would forestall the formation of great parallel sets of strata and wide continuity of shallow-water life.

This will become clearer, and certain additional considerations will be brought into view, if we follow out systematically a normal evolution under each of the two types now basally distinguished.

The systematic evolution of a continent under continuous diastrophism is most easily followed if we accept the view that the mean specific gravity of the continental masses is lower than that of the suboceanic masses and that a certain tendency to isostatic equilibrium between the two arises from this difference of specific gravity—a view strongly supported by concurrent lines of evidence. Probably all will agree to this in some degree at least, whatever limitation or qualification they may wish to impose upon it. If this be accepted, it is not material to our immediate purpose whether the diastrophism is actuated by internal changes of volume, by the transfer of matter and energy from below to the surface, by the transfer of matter from higher to lower levels on the surface, or by all combined, or by other agencies, for the trend toward isostatic equilibrium permeates all and, to the extent of its value, gives shape to their effects in accordance with mechanical laws. The portions of the crust that are already bowed outward, and are at the same time lighter than the average, are inevitably bowed upward under further stress, and the portions that are already sagged, and are at

the same time heavier than the average, are inevitably bowed downward, unless these actions are thwarted by exceptional intercurrent agencies. This inevitable tendency is made the more certain of realization by the constant unloading of the lighter outward-bowed portions and the constant loading of the heavier sagged portions. This must hold true whether the process of deformation be continuous or periodic.

Now, if the process be strictly continuous, as must be the case if a nearly perfect and constant isostatic equilibrium is maintained between the oceanic and continental segments, and between their larger parts among themselves, the evolution of the continents may be followed with logical ease. The continents must rise as they are unloaded and the ocean basins must sink as they are loaded. A secondary result must be a counter movement of the suboceanic material by virtue of which it pushes beneath the eroded continents to compensate their loss. The obviousness of this appears at once if perfect fluidity, the condition of perfect isostasy, is substituted for the existing rigidity that masks the real trend of present tendencies. A perfect adjustment would then take place promptly by vigorous movements of the kind indicated. If a viscous condition were substituted for that of free fluidity, the process would be slower but none the less inevitable. If the viscosity were high, the process would be greatly delayed but would follow the same lines. If the inequalities of specific gravity hold for the larger topographic features, the tendency will be to reproduce them, for the most protuberant portions are most eroded, in general, and suffer most from transportation. They are hence most lightened and must be most elevated in a strictly isostatic process. The continent is thus forced to reproduce itself automatically and, in theory, must continue to do so until the actuating agencies, the primitive differences in specific gravity, are removed.

This alternative cannot apparently be accepted, for the gradational phenomena seem to be decisively against it.

If we turn to the alternative view, and assume that the body of the earth is essentially crystalline, and is rigid up to the elastic limit of the most stressed points of the crystals, and that, aside from strain, the mass does not move until the elastic limit or the solution

or fusion limit of the stressed points is reached, deformation naturally becomes fundamentally periodic. As already remarked by way of qualification, a multitude of minute local periodic motions may so combine as to give the semblance of a continuous motion, but even in this case the precise mode of action and the nature of the effects differ radically from continuous fluidal or plastic flow. Normally, in an elastico-rigid earth, strains should accumulate until they attain marked intensity and should then yield either to a slow massive movement of great magnitude—as is the common case in ordinary diastrophism—or else to a sudden swift movement of less magnitude—as is the case in earthquakes. The latter type is demonstrably non-continuous. There is certainly a period of accumulating strain, with inappreciable motion, followed by quick and often catastrophic movement. Between this class of demonstrative actions and the almost continuous phases of creep, there is believed to be a graded series of cases in each of which the movement is in essence periodic though the general expression varies from nearly continuous movement to sharply periodic movement. In the latter case there may be long intervening stages of relative quiescence.

Periodic movements of all these varieties are consistent with the acceptance of a qualified doctrine of isostasy, i.e., approximate isostasy attained by periodic movement, not complete isostasy attained by continuous movement. This qualified isostasy may be nearly complete, so far as vertical balancing is concerned, just after the periodic movement has ceased. Afterward there is a gradual departure from a strict balancing while stresses are reaccumulating. This leads on to a renewed movement of adjustment and so the periodic process continues. There is in this a rhythmical approach to isostasy.

Now this seems to meet the conditions of the case. It has already been repeatedly urged that the base-leveling process cannot normally reach the stage of an advanced peneplain if continuous warping of the crust is in progress. On the contrary, the crust must hold an approximately static attitude long enough for the gradational process to accomplish the results observed. It has been further urged that there goes with the base-leveling process an

important class of marine deposits and a typical kind of life. So far then as the testimony of these highly important formations bear on the problem of continental rejuvenation, they imply that it was not a continuous steadily progressive process but that it recurred at such wide intervals as to permit great advances toward mature base-leveling as well as the evolution of shelf-seas, of parallel terranes, and of cosmopolitan faunas. All this seems in turn to imply an elastic, rigid, crystalline earth. The form of isostasy that is compatible with this has its working method in periodic approaches to complete isostasy through the successive accumulation and easement of strains in the body of the earth.

THE VOLCANOES AND ROCKS OF PANTELLERIA

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PART II

PETROGRAPHY[1]

The rocks of Pantelleria have been described in modern times only by Foerstner[2] and Rosenbusch.[3] Most of the names assigned by Foerstner are not in accord with present nomenclature or the rock characters. His "phonolites" contain so much silica that no nephelite could form, they being quartz-bearing instead, and his "andesites" contain no soda-lime feldspar, the triclinic feldspar present being a soda-microcline. His "liparites" may best be considered as pantellerites—a group discovered by him, and with well-marked characters, though his synonym, "dacite-liparite," is open to the same criticism as his "andesite." His basalts are normal feldspathic ones.

Rosenbusch describes some of the rocks in detail, while others are only mentioned. He accepts Foerstner's group of pantellerites, to which he refers his "liparites." He remarks on the anomalous character of the "phonolites" and "andesites," but retains Foerstner's names, the highly siliceous composition of the former and the peralkalic character of the latter not being taken into consideration.

The following rocks, named according to the Qualitative System, occur on Pantelleria, their positions in the Quantitative System being also given. They will be described in this order.

[1] The specimens collected by me are supplemented by a set collected by Mr. F. H. Butler of London in 1891, and obtained from him in 1897.

[2] H. Foerstner, *Boll. Com. Geol. Ital.*, 1881, pp. 533–38.

[3] H. Rosenbusch, *Mikr., Phys.*, Vierte Aufl., II, No. 2 (1908), pp. 839, 851, 926, 967, 1039, 1115, 1357. A few very brief descriptions are given by G. T. Prior (*Min. Mag.*, XIII [1903], 254).

Rock Names	Subrangs
Soda trachyte	Kallerudose, I. 4. 1. 4 Nordmarkose, I. 5. 1. 4
Pantelleritic trachyte	Grorudose, II. 4. 1. 3
Comendite	Grorudose, II. 4. 1. 3
Aegirite pantellerite	Grorudose, II. 4. 1. 3
Hyalopantellerite	Varingose, II. 3. 1. 3 Grorudose, II. 4. 1. 3
Basalt	Camptonose, III. 5. 3. 4

SODA TRACHYTE, GIBELÉ TYPE (GIBELAL NORDMARKOSE)

Occurrence.—Lavas of this type, the "andesites" of Foerstner and Rosenbusch, constitute the mass of Montagna Grande and Monte Gibelé, covered in places with beds of pumice or flows of hyalopantellerite. The sheets of lava which make up the scarps of Montagna Grande are massive and often show a roughly columnar structure, while those of Monte Gibelé are, in general, less massive and compact. Along Costa Zichidi they form the uppermost flows, extending westward to the sea near Porto Scauri. Trachyte tuffs do not seem to occur.

Megascopic characters.—Lavas of this type vary from very compact forms to those which are somewhat vesicular. Strictly scoriaceous flows were not observed and even those which are vesicular show streaks of compact rock. The color is a light gray, the feel is rough and the texture highly porphyritic.

Practically the only phenocrysts visible are of alkali feldspar, which form from 25 to 30 per cent of the rock, so that the type is dopatic. These are tabular, highly cleavable, with glistening surfaces, colorless and transparent, and are 1 to 2 cm. in diameter. A few small (1–2 mm.) phenocrysts of black augite are present, but they are so few in number and so inconspicuous as to be negligible. The groundmass is a light ash gray and almost aphanitic, though the lens reveals the presence of light and fewer dark particles, and it is clearly phanerocrystalline. In megascopic habit these rocks resemble so closely some from Ischia and the Phlegrean fields as to be almost indistinguishable from them.

Microscopic characters (*Fig. 6*).—The microscopic characters of this type from Pantelleria have been described by Rosen-

busch,[1] with whose observations my own coincide in nearly all particulars.

The most abundant and largest phenocrysts are of soda-microcline, in thick tables, parallel to *b* (010), or in stout prisms elongated parallel to the vertical axis, either euhedral or subhedral, and often fragmentary. Some of these show a microperthitic structure in very fine lamellae, which resembles the lamellar twinning of the soda-lime feldspars and accounts for Foerstner's designation of "andesite." Typical microcline grating-structure is rare in my specimens, but Carlsbad twinning occurs. In many cases the feldspar phenocrysts are free from inclusions, but in others, especially from Monte Gibelé, there are inclusions of augite (which is often poikilitic and extinguishes simultaneously in isolated patches).

A few small phenocrysts of augite are present. They are mostly stout subhedral prisms, either colorless or light greenish and non-pleochroic. Aegirite-augite is either wanting or very rare, but occurs in the rocks from Costa Zichidi and its neighborhood. No phenocrysts of either hornblende or biotite are present, and small phenocrysts of olivine were only rarely seen, though Rosenbusch notes this mineral as an almost constant phenocrystic accessory. Small irregular grains of magnetite are fairly constant, but always in small amount, this type and the basalts being the only rocks of the island in which it occurs.

The typical groundmass is holocrystalline, but a little glass may be present occasionally, and some of the Gibelé lavas are quite vitrophyric. Soda-microcline makes up the greater part, either in short, small laths or anhedra, both being present in the same specimen. A flow texture is more or less well developed, though this seldom assumes a typically trachytic fabric.

The mafic[2] minerals in the groundmass are pyroxene and hornblende. The former is a colorless augite, less often greenish and aegiritic, in prisms or more abundant anhedra. No hypersthene

[1] H. Rosenbusch, *Mikr. Phys.*, II, No. 2 (1908), p. 1115; on p. 926 he speaks of them as trachytes.

[2] Equivalent to ferromagnesian; cf. Cross, Iddings, Pirsson, and Washington, *Jour. Geol.*, XX (1912), 560.

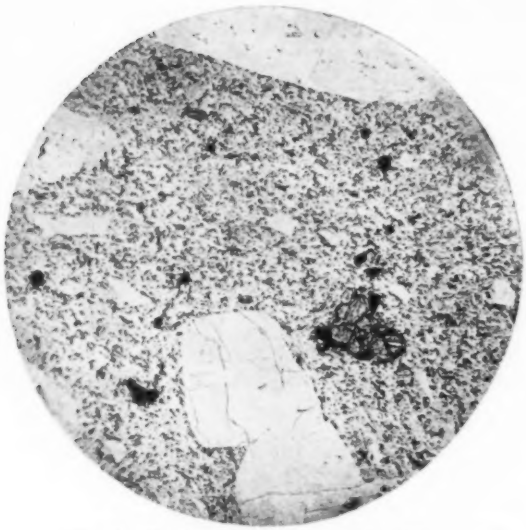

FIG. 6.—Trachyte, Montagna Grande. × 20

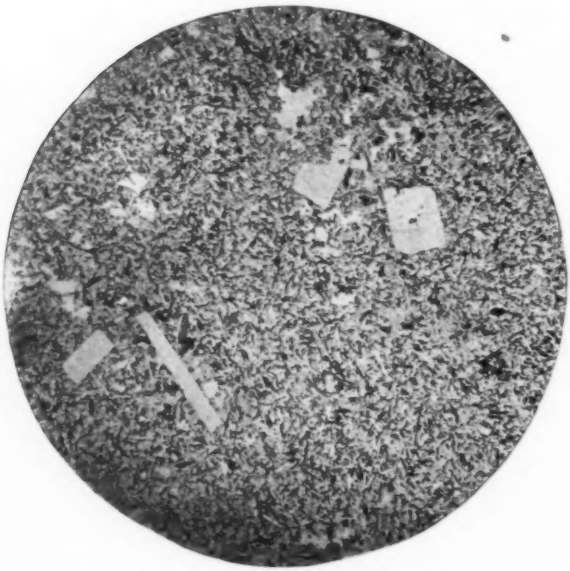

FIG. 7.—Pantelleritic trachyte, Costa Zeneti. × 20

could be identified by me. The hornblende is a very dark chestnut brown, intensely pleochroic, in small prisms and anhedra, which show no cleavage. It is probably cossyrite, as suggested by Rosenbusch, or possibly kaersutite, which has been found on Linosa. The latter is suggested by its pure brown color, without the reddish tinge so characteristic of cossyrite, and the nearly or quite parallel extinction of the small prisms in some specimens from Montagna Grande. The hornblende frequently surrounds and is later than some of the groundmass feldspars, while the pyroxene belongs to an earlier period of crystallization.

No magnetite is present in the groundmass of any of my specimens, but flakes of orange or blood-red hematite occur in some cases, which do not seem to be secondary. A little quartz may be detected in some cases as an interstitial residuum, but its amount is small.

Hyaline facies.—A specimen from the surface of a flow at Costa Zichidi, which is somewhat vesicular, is different from the others. In thin section are the usual feldspar phenocrysts, with rounded ones of red-brown cossyrite, a few of aegirite-augite, but none of augite. The groundmass consists largely of a pale yellowish glass, containing minute laths of feldspar. This glass is thickly crowded with peculiar dendritic growths of a deeper brown color which often assume a globular form from 0.2 to 0.5 mm. in diameter, and again larger irregular areas. Feldspar phenocrysts usually form the nucleus of these. They are made up of small grains seldom more than 0.01 mm. in diameter, either equant or elongated.

Toward the center of the spherulites the grains are thickly crowded, but they separate at the borders, which consist of small, irregular, radially divergent tongues and processes. The grains are light yellow in color with rather high birefringence, the areas showing a faint aggregate double refraction. Their extremely small size makes optical determination difficult, but they are probably an aegiritic augite.

Chemical composition.—Analyses were made of a specimen from a massive flow near the base of the southwest scarp of Montagna Grande, below Rione Miliac, of one from the crater of Monte

Gibelé obtained from Mr. Butler, and of one from the top of Costa Zichidi. Two by Foerstner are also given, one of the Montagna Grande rock and one of a flow at Porto Scauri.

ANALYSES OF TRACHYTE, GIBELE TYPE

(GIBELAL NORDMARKOSE)

	A	B	C	D	E	Aa	Ba	Ca
SiO_2	63.43	63.30	65.27	61.47	61.43	1.057	1.055	1.088
Al_2O_3	16.31	16.38	13.50	18.09	17.51	.160	.161	.132
Fe_2O_3	2.04	2.54	4.40	5.14	5.11	.013	.016	.028
FeO	3.14	2.36	2.52	3.06	2.30	.043	.033	.035
MgO	0.78	0.84	0.55	1.32	0.54	.020	.021	.014
CaO	1.70	1.62	0.85	3.00	2.45	.030	.029	.015
Na_2O	6.71	6.36	5.19	5.85	6.22	.108	.103	.084
K_2O	4.31	4.41	4.21	2.83	3.95	.046	.047	.045
H_2O+	0.18	0.83	1.98	n.d.	n.d.	....	....	....
H_2O-	0.26	0.10	0.14	n.d.	n.d.	....	....	....
TiO_2	1.19	0.71	1.09	n.d.	n.d.	.015	.009	.014
ZrO_2	0.06	....	....	....	....	....	....	....
P_2O_5	0.20	0.30	0.17	n.d.	n.d.	.001	.002	.001
SO_3	0.05	....	....	....	....	....	....	....
MnO	0.04	n.d.	0.27	n.d.	n.d.	.001	....	.001
BaO	0.05	....	....	....	....	....	....	....
	100.45	99.75	100.14	100.76	99.51	....	....	....

A. Below Rione Miliac, Montagna Grande. H. S. Washington, analyst.
B. Crater of Monte Gibelé. H. S. Washington, analyst.
C. Costa Zichidi. H. S. Washington, analyst.
D. Montagna Grande. H. Foerstner, analyst. *Zeits. Kryst.*, VIII (1884), 155.
E. Porto Scauri. H. Foerstner, analyst. *Zeits. Kryst.*, VIII (1884), 164.
Aa, Ba, Ca, mol numbers[1] of A, B, C, respectively.

The first two analyses are typical ones of distinctly sodic trachytes, slightly high in silica and with very high TiO_2, considering the salic characters of the rocks. They are remarkably alike and indicate a general uniformity in the flows of the Gibelé volcanoes, since A, coming from the foot of the Miliac scarp, must be considerably older than that from the Gibelé crater. The analysis of the Zichidi rock C resembles them in general features, but is higher in silica and ferric oxide and lower in alumina, magnesia, lime, and soda. Except for the lower soda it shows affinities toward the pantelleritic trachytes.

Foerstner's analyses cannot be regarded as very satisfactory, partly because of the non-determination of water, titanium, and

[1] This term is used instead of molecular ratios, following Wright and Van Orstrand (*Jour. Wash. Acad. Sci.*, III [1913], 233).

phosphoric oxides, and partly because of certain features which will be discussed later. They indicate, however, that the silica is probably lower in some of these trachytes than in my analyzed specimens.

The norms of A, B and C are given below:

	A	B	C
Q	3.90	5.58	17.10
Or	25.58	26.13	25.02
Ab	56.59	53.97	44.01
An	1.67	3.06	0.83
Di	4.83	2.48	1.94
Hy	1.59	1.96	0.50
Mt	3.02	3.71	5.57
Hm	....	....	0.64
Il	2.28	1.37	2.13
Ap	0.34	0.67	0.34
	99.80	98.83	98.08
Rest	0.64	0.93	2.12
	100.44	99.76	100.20

The magmatic symbol of A is I(II).5.1.4, that of B is I(II)."5.1"."4, and that of C is I(II).4.1.(3)4, using the notation recently proposed[1] to indicate the exact position of a rock magma in each division of the Quantitative System. The first two are in nordmarkose, in the persalane class but transitional toward dosalane, and hence are strictly to be called umptekose-nordmarkose, B not being as centrally placed in the other divisions as A. The excess of silica is so small as to be negligible. The Zichidi rock also falls in the same place as regards the class, but is in order 4, and its dosodic subrang is transitional toward the sodipotassic one, so that it is a liparose-kallerudose. Here the amount of normative quartz is notable, indicating its tendency toward the pantelleritic trachytes. It is to be noted that these trachytes (and the basalts) are the only Pantelleria rocks which show normative anorthite, so that, in spite of the presence of aegirite-augite, no acmite appears in the norm.

[1] Cross, Iddings, Pirsson, and Washington, *Jour. Geol.*, XX (1912), 554. I use the sign" to indicate that the position is intermediate but not transitional; that is, between the central portion and the transitional border.

Mode.—Owing to the fine grain and complex texture of the groundmass, an exact estimate of the mode by microscopic measurement is impossible. When the norm is compared with the thin sections the amount of mafic minerals—pyroxene and hornblende—present is seen to be much larger than that of the normative pyroxene, while but a very small proportion of the normative ores is present in the mode. The mode is, therefore, somewhat abnormative, and it is clear that readjustments of the norm to estimate the mode must consist chiefly in combining the normative ores and pyroxenes with some silica and albite. These readjustments cannot be made with certainty, as two pyroxenes and a hornblende are present and their composition is unknown. But the amounts of these are small and, taking the thin sections into consideration, the following will represent fairly well the relative amounts of minerals present in my analyzed specimens from Montagna Grande A and Zichidi B.

	A	B
Quartz	3	13
Soda-microcline	83	70
Aegirite-augite	7	9
Hornblende	5	6
Magnetite	2	2
	100	100

These rocks are evidently slightly quartzose soda-trachytes, that of Zichidi containing so much quartz as to be transitional to the rhyolites. As this, however, is confined to the groundmass and is not at all prominent even there, it had best be classed with the trachytes. Their sodic character is chiefly evident in the feldspars, the augite is only slightly aegiritic, and the amount of soda-amphibole (cossyrite) very small, in these two latter respects differing from the next type.

Such alkali-trachytes have been called by Rosenbusch augite trachytes of the Ponza type. These of Pantelleria differ widely from the true Ponza trachytes, which Rosenbusch has described and specimens of which I have studied, in the total absence of biotite, either as such or as augite-magnetite aggregates represent-

ing original biotite crystals. The Ponza trachytes also differ chemically, especially in a higher potash content, judging from the only analyses of them which appear to have been made.[1] As occurrences of these sodic trachytes are becoming rather common, it might be well to call the true Ponza type, with biotite, *ponzite*, and those of the Pantelleria type, *gibelite*.

PANTELLERITIC TRACHYTE, ZENETI TYPE (ZENETAL GRORUDOSE)

Occurrence.—Rocks of this type, which are the "phonolites" of Foerstner, form flows seen in the lower portions of the internal scarps of the large, first-period caldera, notably at Costa Zeneti and Costa Zichidi. The type also occurs near the base of the more precipitous portions of the coast line, as near Punta Pozzolana and Cala Cinque Denti on the north, the coast from Punta Tracino to Punta Kharace on the east, and various stretches on the south and southwest. These coastal occurrences presumably are extensions of flows, the more central portions of which form the bases of the internal scarps, and rocks of this type may be regarded as the earliest known outpourings of the Pantelleria volcano.

Megascopic characters.—Rocks of this type are of a rather dark-gray color, and are usually compact, but slightly vesicular forms occur. The only phenocrysts visible are very small (1–2 mm.), glistening, white tables of feldspar, which are not conspicuous and make up less than 5 per cent of the mass. Here and there are equally small, black grains of augite, but the amount of these is quite negligible. The slightly brownish, dark-gray groundmass is dense and aphanitic, and in some specimens shows evidence of vitreous texture.

Microscopic characters (*Fig. 7*).—A brief description of the microscopic characters of some of these rocks has been given by Rosenbusch,[2] which coincides with my own observations and the few statements of Foerstner.[3]

The most prominent phenocrysts are soda-orthoclase, though they are not large or abundant. They are euhedral and tabular

[1] C. Doelter, *Akad. Wiss. Wien*, XXVI, 1875, pp. 148, 151.

[2] H. Rosenbusch, *Mrik. Phys.*, II, No. 2 (1908), pp. 839, 967, 1115.

[3] H. Foerstner, *Boll. Com. Geol. Ital.*, 1881, p. 534.

parallel to *b* (010), often showing Carlsbad twinning. A few small, euhedral, stout prisms of a rather bright-green, pleochroic aegirite-augite are also present, but no cossyrite phenocrysts were observed in my specimens or noted by Rosenbusch.

The groundmass is typically holocrystalline, and consists of numerous small prisms and anhedra of aegirite and hornblende in a colorless base of quartz and alkali-feldspar. Most of the aegirite is in the form of euhedral to subhedral prisms, never more than 0.2 mm. long and about 0.05 mm. thick, and usually much smaller, while small anhedral grains are also common. Its color is light green, extremely pale in the smaller individuals, and it is distinctly pleochroic, especially in the larger and more deeply colored individuals: **a** grass-green, **b** and **c** lighter yellowish green. In the smaller and paler crystals the pleochroism is not well-marked. The deeper colored individuals show extinction angles $c \wedge \mathbf{a}$ up to 24°, so that they are to be regarded as aegirite-augite, while in the small prisms the angle is much less and they may be considered to be almost or quite pure aegirite, though extremely light in color.

The hornblendes are by no means as well formed as the pyroxenes, and while many of them show a prismatic development, definite crystal faces are lacking, and many individuals are small, anhedral grains. Cleavage is not developed. The color is a deep chestnut brown and the mineral is highly pleochroic, an almost opaque brown and a light hair-brown. Between crossed nicols this hornblende often shows a peculiar, brilliant, copper color. This hornblende is presumably the cossyrite which forms phenocrysts in other Pantellerian lavas, as is suggested by Rosenbusch, though the pleochroism is somewhat different. A few small, anhedral grains of grayish blue, apparently arfvedsonitic hornblende, were seen in some sections, but their presence is exceptional.

The pyroxenes and hornblende are present in about equal amount, but there seems to be usually more of the former. They are often clustered in somewhat curved, narrow groups, the "dendrites" of Foerstner, which produce what might be called a wreath texture. The colorless base, seen between crossed nicols and

rather high powers, resolves itself into an aggregate of very small alkali-feldspar individuals, which vary in form from euhedral prisms to anhedral grains, imbedded in an interstitial cement of quartz. This last is often micropoikilitically developed,[1] areas with uniform extinction inclosing the small feldspars. This quartz is doubtless the mineral called nephelite, unequivocally by Foerstner and doubtfully by Rosenbusch, but which the large

ANALYSES OF PANTELLERITIC TRACHYTE

(ZENETAL GRORUDOSE)

	A	B	Aa	Bb
SiO_2	64.54	63.77	1.076	1.063
Al_2O_3	11.49	11.18	.113	.110
Fe_2O_3	5.14	5.02	.032	.031
FeO	2.99	2.58	.042	.036
MgO	0.89	0.51	.022	.013
CaO	0.64	1.37	.012	.025
Na_2O	5.46	5.55	.089	.090
K_2O	4.66	4.35	.050	.047
H_2O+	1.11	2.72	....	....
H_2O-	2.12	1.28	....	....
TiO_2	0.90	0.94	.011	.012
ZrO_2	0.08	....	....	....
P_2O_5	0.16	0.14	.001	.001
O_3	0.17	....	....	....
MnO	0.13	0.26	.002	....
	100.48	99.67	....	....

A. Base of Costa Zeneti. H. S. Washington, analyst.
B. Base of Punta Pozzolana. H. S. Washington, analyst.
Aa. Mol number of A. Ba. Mol number of B.

amount of free silica present in the norm shows cannot exist in the rock. Biotite is not present and no grains of magnetite were seen.

Hyaline facies.—A specimen of a hyaline facies of this type merits brief description. It forms a flow at sea-level at Punta Pozzolana.[2] It is compact, very dark grey, and with very few feldspar phenocrysts visible. In thin section these feldspars show no feature worthy of special note, and phenocrysts of aegirite-augite and hornblende are extremely rare. The groundmass is

[1] Cf. P. Geijer, *G. För. Stockh. Förh.*, XXXIV (1913), 51.

[2] At Punta Pozzolana I found no rock corresponding to the "trachydolerite" mentioned by Prior from this locality.

dohyaline and hyalopilitic, composed of a colorless or slightly brownish glass thickly felted with minute, slender, prismatic microlites of an almost colorless mineral, which is most probably an aegiritic pyroxene. There are also some minute laths of alkali feldspar, but not a trace of hornblende could be detected in the groundmass.

Chemical composition.—Two analyses were made of this type, and are given in the annexed table.

The rocks are distinctly higher in silica and ferric oxide and lower in alumina and soda than the preceding type, lime being lower in the main occurrences, and ferrous oxide, magnesia, potash, and titanium about the same. Foerstner (p. 534) gives a partial analysis of a Zeneti "phonolite"; $SiO_2=67.8$, $Na_2O=6.0$, $K_2O=3.8$. The high silica here is probably approximately correct, and is significant.

	A	B
Q	15.12	14.34
Or	27.80	26.13
Ab	33.01	33.01
Ac	11.55	12.47
Di	1.76	5.20
Hy	3.38	1.42
Mt	1.62	0.93
Il	1.67	1.82
Ap	0.34	0.34
	97.25	95.76
Rest	3.48	4.00
	100.73	99.76

The two rocks fall well within the subrang grorudose, II.4.1.3, though that of Punta Pozzolana is intermediate toward pantellerose, II.4.1.4. The chief interest of these norms lies in the fact that, in spite of the dominance of soda over potash shown in the analysis, the rocks are sodipotassic in their classificatory position. This is due to the small amount of alumina which necessitates the formation of femic acmite. The amount of alumina is too high, or that of soda too low, to permit of the formation of normative sodium metasilicate, which we shall meet with in the pantellerites.

Mode.—The groundmass is too fine grained, and the texture too confused, to permit of satisfactory measurements by Rosiwal's method of the relative amounts of the constituent minerals, but a recalculation from the norm, taking the thin sections into consideration, yields the following mode for the Zeneti trachyte:

Quartz	15
Soda-microcline	63
Aegirite-augite	12
Hornblende	10
	100

These trachytes are in many ways intermediate between the Gibelé trachytes and the pantellerites, so that the name of pantelleritic trachyte is applicable to them.

COMENDITE, NERA TYPE (NERAL GRORUDOSE)

Occurrence.—Flows of this rock—the "white liparite" of Foerstner—form sheets above those of the preceding type. They are met with at various points along the inner scarp of the caldera wall, notably at Cuddia Nera, where two superposed flows are seen, the upper being platy in structure and the lower distinctly columnar and the rather narrow columns often curved. They are capped by a thin sheet of the green pantellerite, next to be described. The type also occurs in the scarp of Costa Zichidi, on the west side of the Val di Monastero, and on the southeast side of the Valle Silhoumen, according to Forestner, though I did not see it here. Foerstner mentions it at the so-called Polveriera, the ancient citadel of Cossyra, southeast of the town, but probably terracing for vineyards has since covered the exposure as I observed here only basalts from the Sant' Elmo flow. Along the steep parts of the coast flows of this rock are seen, occurrences being at Punta Pozzolana, Cala Cinque Denti, and Cala Porticello. At the first of these the rock is rather tuffaceous, is covered by a yellowish pantelleritic tuff, and overlies a flow and scoria bed of black and green pantellerite, while at the sea-level is the vitrophyric zenetal grorudose described above. This type is briefly described by Rosenbusch.[1]

[1] H. Rosenbusch, *op. cit.*, p. 839.

Megascopic.—The rocks are compact and generally a very light gray, almost white, though a flow at Cuddia Nera is light pinkish through weathering; small phenocrysts of feldspar are numerous, with fewer of black hornblende and augite. The groundmass is very fine grained, somewhat dull, and phanerocrystalline.

Microscopic.—The largest phenocrysts are of soda-orthoclase, which are tabular parallel to *b* (010), and are like those already described. More interesting are those of hornblende which form not more than about 2 per cent of the rock. These are euhedral to subhedral, slender prisms, about 0.5 mm. long by 0.2 mm. thick. They have the faces *m* (110) and *b* (010) well developed, but no terminal planes. The prismatic cleavage is good. When these phenocrysts occur in the groundmass they are almost invariably surrounded by a narrow border of finely granular hornblende of somewhat lighter color, which is absent from the few included in feldspar phenocrysts.

The color of the hornblende is a rather dark chestnut brown, without the tinge of red which is so characteristic of the cossyrite of the various types of pantellerites. The pleochroism is very strong; **c** and **b** dark brown, or almost black, **a** light yellow brown. It was difficult to determine the extinction angle accurately owing to the intense absorption, but values of $\mathbf{c} \wedge c$ up to 20° were observed. Though the pleochroism differs from the normal cossyrite, the other characters, as well as the chemical composition deduced from the norm, show that this hornblende is a cossyrite and not a kaersutite which it somewhat resembles.

A few subhedral phenocrysts of a bright-green, slightly pleochroic aegirite-augite are present, and in a few sections rare anhedral olivine phenocrysts.

The groundmass is holocrystalline and is mostly composed of alkali-feldspar and quartz. The former is usually in the form of minute tables, giving rise to lath-shaped sections, though some anhedral grains occur. The quartz appears as small patches, about 0.1 to 0.2 mm. in diameter, usually irregular in outline but sometimes roughly rounded, which include feldspar grains microkoikilitically. Scattered abundantly through this quartz-feldspar

base are very small crystals of green aegirite-augite and the pleochroic brown hornblende, the latter being more abundant than the former. Both of these mafic minerals form highly irregular shreds and anhedra and are seldom if ever prismatically developed, nor do they occur in the wreathlike aggregates so characteristic of the preceding type. No magnetite is to be seen in any of the specimens nor did I see the biotite mentioned by Rosenbusch.

Chemical composition.—An analysis was made of the comendite which forms the lowest, columnar flow at Cuddia Nera, this being the freshest and that which best shows the brown hornblende. An analysis of a "liparite" from Cala Porticello by Foerstner is also given, but it is very doubtful if it is of the same type as it differs much in chemical composition and he gives no description.

ANALYSES OF COMENDITE, NERA TYPE

(NERAL GRORUDOSE)

	A	B	Aa
SiO_2	72.21	67.18	1.204
Al_2O_3	9.72	14.18	.096
Fe_2O_3	3.26	4.00	.020
FeO	1.07	2.48	.015
MgO	0.29	0.34	.007
CaO	0.82	2.78	.014
Na_2O	4.42	5.89	.071
K_2O	4.98	4.01	.053
H_2O+	1.96	n.d.	.....
H_2O-	0.24	n.d.	.....
TiO_2	0.62	n.d.	.008
P_2O_5	0.10	n.d.	.001
MnO	0.05	n.d.	.001
	99.74	100.86	.....

A. Lowest flow, Cuddia Nera. H. S. Washington, analyst.
B. "Liparite," Cala Porticello. H. Foerstner, analyst. *Zeits. Kryst.*, VIII (1884), 133.
Aa. Mol number of A.

This type differs from those described previously in the high silica, which is the highest found by me in any rock of the island. The predominance of ferric over ferrous oxide may be noted, and the small amounts of magnesia and lime. This rock is also the only one analyzed by me which shows a greater percentage of potash than of soda, though molecularly the latter is present in greater quantity. Foerstner's partial analysis[1] is of interest in

[1] *Boll. Com. Geol. Ital.*, 1881, p. 535.

this connection: $SiO_2=73.1$, $Na_2O=2.5$, $K_2O=5.0$. This rock from the Polveriera shows about the same amounts of silica and potash as that from the Cuddia Nera, but soda is somewhat lower, though in both the percentage of potash is greater than that of soda, and molecularly they are present in about equal amount. The distinctly high potash is noted by Foerstner as a character of the rock type.

Norm.—The norm of the Cuddia Nera rock is as follows:

	Norm
Q	31.14
Or	29.47
Ab	22.01
Ac	9.24
Ns	1.10
Di	2.57
Hy	0.46
Il	1.22
Ap	0.34
	97.55
Rest	2.24
	99.74

The type falls within the dosalane class but is transitional to persalane, and is nearly on the border of order 3. The rang is decisively peralkalic, no salic lime being present, since acmite exists in the norm, and the subrang is also clearly sodipotassic. It is therefore in (I)II, (3)4.1.3, so that the type should be called a varingose-grorudose. It will be seen that acmite constitutes the greater part of the femic minerals, and the presence of sodium metasilicate in small amount is to be noted as this is characteristic of the pantellerites, being correlated in the mode with the presence of cossyrite.

Mode.—Through the presence of the hornblende the mode is somewhat abnormative. From recalculation of the norm and study of the thin sections it may be expressed approximately as follows, the cossyrite being assumed to have the composition of that analyzed by Dittrich:[1]

[1] J. Soellner, *Zeits. Kryst.*, XLVI (1909), 540.

Quartz	30
Soda-microcline	51
Cossyrite	12
Aegirite-augite	7
	100

Though the type very closely resembles the pantellerites, yet it seems advisable to follow the suggestion of Rosenbusch and call these rocks comendites, partly because of the very high silica, partly because of the high potash, and partly because of the megascopic characters and the microscopic texture of the groundmass.

AEGIRITE PANTELLERITE, SANTELMO TYPE (SANTELMAL GRORUDOSE)

Occurrence.—Lavas of this type (the "crystalline pantellerite" of Foerstner) are abundant on the island. In the north it forms flows from Monte Sant' Elmo, an area to the south of Monte Gelkhamar, and a somewhat more extensive one from near Cuddia Bonsulton northeasterly to Costa Zeneti and Cuddia Nera (forming the upper part of these), Rione Khadingia, and beyond to the coast near Punte Pozzolana and Karuscia. In the south and southeast it constitutes the mass of Cuddia Attalora and the slopes from Cuddie dietro Isola and Serra Ghirlanda to the sea. As noted above the flows of this pantellerite were the last from the early volcano, before the great caldera-forming eruption. These lavas are often accompanied by yellow tuffs. Flows of this type are generally pahoehoe, and in places the lava is made up of mingled streaks of this and the succeeding type.

Megascopic characters.—These lavas are often platy, generally compact, but again somewhat vesicular. The type is distinctly but finely porphyritic. The aphanitic, dull, and apparently cryptocrystalline groundmass is of a light yellowish-green color, which varies somewhat in different specimens. Through this are sprinkled many small (1–3 mm.), glistening, white feldspar phenocrysts, and few smaller stout prisms of black pyroxene and hornblende. Some of these are also to be seen in the crevices and vesicles, with occasional small tables of tridymite.

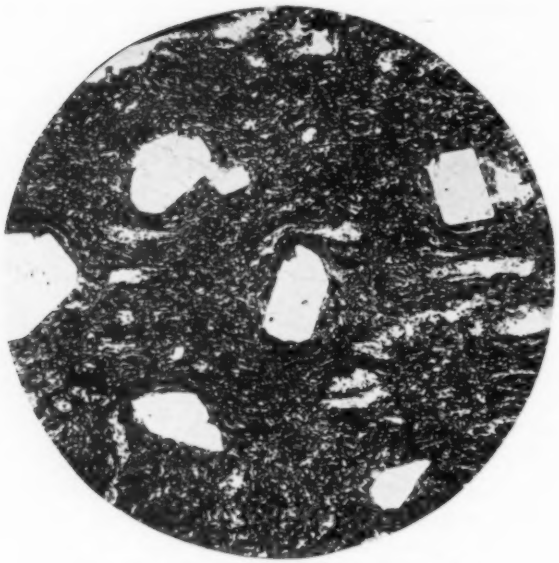

FIG. 8.—Aegirite pantellerite, Costa Zeneti. × 20

FIG. 9.—Hyalo pantellerite, Khagiar. × 20

Microscopic characters (*Fig. 8*).—The pantellerites of Pantelleria have been described in great detail by Rosenbusch,[1] who devotes especial attention to this type. Except for some minor details my observations fully bear out his descriptions.

The soda-microcline phenocrysts are not numerous in the sections. In general they are thick, tabular parallel to *b* (010), and euhedral, but are often fragmentary. They show no microcline or perthite structures and no albite twinning lamellae, but Carlsbad twins are frequent. Inclusions are rare.

In most of the specimens cossyrite phenocrysts are fairly common, while in others they are wholly wanting. They are stoutly prismatic and vary from 0.2 to 0.4 mm. in length. Originally euhedral, most of them show rounded outlines, especially at the terminations, and some are thus reduced to ovoidal forms. This is probably due to resolution by the magma, as suggested by Rosenbusch. Their color is a very deep reddish brown, with internal pleochroism; **c** brownish black, **b** deep chestnut brown, **a** red brown. A few small phenocrysts of a pleochroic, grass-green aegirite-augite are present. Magnetite grains are wholly absent, but there are a few zircons. I could find none of the olivine or apatite mentioned by Rosenbusch.

This rock type has a very peculiar and highly characteristic groundmass. Under low powers it is light, yellowish white and almost opaque through the abundance of patches and streaks of a dustlike substance, which commonly show a well-developed flow texture. This invariably occupies most of the section, and in the narrow interstices is a colorless substance with feeble, diffuse birefringence.

Under high powers the opaque substance is resolved into a felt of extremely minute, transparent, nearly colorless, prismatic microlites. These must be considered to be aegirite (as suggested by Rosenbusch), though their extreme tenuity renders determination of their optical characters very difficult. It is, of course, to the presence of this aegirite felt that the greenish color of the rock is due. No cossyrite or other hornblende was observed as a groundmass constituent. The colorless base is now seen to be generally holocrystalline, and formed of an intimate mixture of very minute

[1] H. Rosenbusch, *op. cit.*, pp. 852–54.

grains of feldspar and quartz, though colorless glass is present in small amount in some sections.

Pantellerite pumice.—With this type of pantellerite may be briefly described a pumice which covers a considerable area near the center of the island, about the summit of Montagna Grande and Cuddia Mida, between Monte Gibelé and Serra Ghirlanda, and in isolated patches elsewhere. It is whitish or cream colored, becoming a brownish yellow on wetting; highly vesicular, floating easily on water. Equant phenocrysts of alkali feldspar (2–5 mm.) are rather abundant, but none of mafic minerals. A flow texture is usually well developed.

In thin section this pumice is seen to be perhyaline. A few of the feldspar phenocrysts, and still fewer and smaller ones of aegirite-augite are present. The glass base is clear and colorless, carrying only extremely small amounts of "dust" and very rare microlites of feldspar and pyroxene. No hornblende is present.

Chemical composition.—Two analyses of this type of pantellerite, and one of the pumice were made. With them are given two by Foerstner and one by Abich of pumice.

These are all consistently higher in silica and ferric oxide, and lower in alumina, lime, and magnesia, than the trachytes described previously. The only difference of note between my two analyses of the type is the alumina, the higher figure in B being partly compensated for by the slightly higher iron oxides of A. Otherwise they are almost identical. It will be observed that TiO_2 is high for such silicic rocks. Attention must be called here to the relation of the iron oxides, the percentage of Fe_2O_3 being much higher than that of FeO in both. The analysis of the pumice is closely like the others, though lower in silica, and the proportion of ferric oxide is greater. It is chiefly on this account and because of the colorless glass that it is placed with the Santelmal type. The analyses of Foerstner are unsatisfactory in their incompleteness, and also seem to suffer from the usual systematic errors. It will, however, be observed that his iron oxides, though higher than mine, show much more Fe_2O_3 than FeO. While the analysis of Abich is, of course, unsatisfactory according to modern standards, yet, considering its date, it is very creditable, the alkalies alone being improbable.

ANALYSES OF AEGIRITE PANTELLERITE

(SANTELMAL GRORUDOSE)

	A	B	C	D	E	F	Aa	Ba	Ca
SiO_2	70.14	69.79	67.32	70.30	67.48	68.11	1.169	1.163	1.122
Al_2O_3	8.61	11.91	9.55	6.32	9.70	8.21	.084	.117	.094
Fe_2O_3	6.01	5.35	6.73	9.23	7.42	8.23	.038	.034	.042
FeO	2.73	1.43	0.81	1.40	2.21	....	.038	.020	.011
MgO	0.20	0.25	0.20	0.89	0.77	0.37	.005	.006	.005
CaO	0.45	0.25	0.20	0.84	1.45	0.14	.088	.004	.004
Na_2O	5.44	5.66	5.71	7.70	7.21	8.32	.088	.091	.092
K_2O	4.20	4.59	4.48	2.50	2.94	1.60	.045	.049	.048
H_2O+	0.35	0.17	3.15	0.82	0.96	1.73	....	....	....
H_2O-	0.17	0.04	0.49	n.d.	n.d.	....	....	....	....
TiO_2	0.86	0.89	0.59	n.d.	n.d.	1.23	.011	.011	.007
ZrO_2	0.14	....	....	....	....	....	....	....	....
P_2O_5	0.12	0.13	0.08	n.d.	n.d.	n.d.	.001	.001	.001
SO_3	0.06	....	....	....	....	....	....	....	....
MnO	0.38	0.20	0.24	n.d.	n.d.	Cl= 0.70	.005	.003	.003
BaO	none	....	....	....	....	CH_4 = 0.66	....	....	....
	99.86	100.66	99.55	100.00	100.14	99.20	....	....	....

A. Monte Sant' Elmo. H. S. Washington, analyst.
B. Costa Zeneti. H. S. Washington, analyst.
C. Pumice. Rione Buccarame. H. S. Washington, analyst.
D. Khartibugal. H. Foerstner, analyst. *Zeits. Kryst.*, VIII (1884–), 173.
E. Monte Sant' Elmo. H. Foerstner, analyst. *Zeits. Kryst.*, VIII (1884–), 186.
F. Pumice of Pantelleria. H. Abich, *Vulk. Ersch.*, 1841, Taf. III.
Aa. Mol numbers of A. Ba. Mol numbers of B. Ca. Mol numbers of C.

The norms of the first three rocks are as follows:

	A	B	C
Q	27.60	21.78	22.44
Or	25.02	27.24	26.69
Ab	20.44	35.63	24.10
Ac	17.56	10.63	19.40
Ns	1.34	....	0.49
Di	1.21	....	....
Hy	4.10	0.60	1.03
Mt	....	2.09	....
Il	1.67	1.67	1.42
Hm	....	0.32	....
Ap	0.34	0.34	0.34
	99.28	100.30	95.91
Rest	0.72	0.21	3.64
	100.00	100.51	99.55

The Sant' Elmo pantellerite, therefore, falls in varingose, II.3(4).1.3, owing to the large excess of silica, but transitional to

grorudose, while the other two fall well within grorudose, II.4.1.3, B being intermediate toward liparose and pantellerose. Acmite predominates strongly among the femic minerals, and the amount of sodium metasilicate is very small or nothing, in which respect this type of pantellerite differs from that next to be described.

Mode.—Owing to the fineness of the grain the mode cannot be determined by optical means but can be recalculated from the norm, the same assumption being made as to the cossyrite as before.

A		B	
Quartz	28	Quartz	20
Or_5Ab_4	45	Or_4Ab_5	63
Aegirite	17	Aegirite-augite	14
Cossyrite	10	Cossyrite	3

This type, being holocrystalline, may be regarded as typical pantellerite, the cenotypal equivalent of Brögger's grorudite, the analyses of which are closely similar.

HYALO-PANTELLERITE, KHAGIAR TYPE (KHAGIARAL VARINGOSE AND GRORUDOSE)

Occurrence.—This type is, in general, later than the preceding, belonging to the last period of the second phase after the tilting of the Montagna Grande block and before the eruption of basalts. In certain localities, as at Sant' Elmo, Cuddia Nera, and, in the south of the island, flows of the Santelmal type show streaks and patches of this glassy black type. The cones and flows of this type are found around the tilted Montagna Grande block, at Cuddie Randazzo and Gelfiser, with their respective great flows, at the north, Gelkhamar and Sciuvechi at the northwest, the two small Monti Gibile to the west, Fosso del Russo and the lavas of Rione Benimingallo to the south, and those of Rioni Mueggine and Khamma to the east. These lava flows are of the *aa* type, the blocks being generally angular.

Megascopic characters.—The specimens from most of the occurrences are very uniform. They are black, highly vitreous rocks, composed of a pure black, generally lustrous, glass groundmass, which in some specimens is locally slightly iridescent due to incipient alteration. In the specimen from Cantina Ziton the glassy groundmass is dull and somewhat waxy in luster. This

glass is very thickly sprinkled with small (1–3 mm.), rectangular, nearly equant phenocrysts of white glistening feldspar, which do not show any flow arrangement. They are in some cases so abundant as to be present in almost as great amount as the glass, but typically the rock is dopatic. A few perpatic forms were seen—black obsidians with very rare and small feldspar phenocrysts. These pure obsidians do not seem to form flows, but occur as blocks in the yellow pantelleritic tuffs. In all the specimens examined by me this black glass is brownish in thin edges, and I saw none of the green glass noted by Rosenbusch and Foerstner.

Microscopic characters[1] (*Fig. 9*).—The numerous soda microcline phenocrysts are mostly euhedral, in stout prisms parallel to *c* or tables parallel to *b* (010), but a few are rounded as by magmatic corrosion and some are fragmentary. They are usually quite free from inclusions, but a few contain minute crystals of aegirite-augite or cossyrite. Phenocrysts of two kinds of pyroxene are present, both in very small amount. One is an almost colorless or very pale greenish-gray diopside; the other a bright grass-green, distinctly pleochroic aegirite-augite. Both occur as stout prisms, but subhedral with rounded edges, and the former is likely to be much corroded. The cossyrite phenocrysts are more abundant than those of pyroxene and resemble those of the preceding type. No arfvedsonite was seen and lime-soda feldspars and magnetite grains are wholly absent. Olivine is also wholly wanting, except in a specimen from Cantina Ziton, from a flow south of, and apparently from, Fosso del Russo. Olivine phenocrysts (about 2 per cent) occur in this in small euhedral or subhedral, slightly corroded crystals, carrying a few magnetite inclusions. No cossyrite occurs in this rock.

The groundmass is highly vitreous, the glass being brownish, never greenish in my specimens. In most specimens this glassy groundmass is dohyaline, small prisms of alkali-feldspar, with fewer of cossyrite and augite, being abundant. A flow texture is always well marked, shown by the fluidal arrangement of the microlites, as well as by streaks of more or less crystalline groundmass, some of which are almost holocrystalline and correspond to the groundmass of the Santelmal type.

[1] Rosenbusch describes this type with the preceding (*op. cit.*, p. 852).

The specimen from Cantina Ziton has a perhyaline groundmass —an almost colorless glass, slightly mottled with "dust" but free from microlites, spherulitic through the presence of yellow-brown cumulites, which are almost opaque and without action on polarized light. These are sometimes isolated and globular, and elsewhere in streaks with marked flow texture. They resemble the spherulites of some Hungarian liparites.

The obsidian is an almost absolutely pure, perfectly clear, light-brownish glass, less than 1 per cent of crystals being present, very small euhedra of alkali-feldspar and rare augite microlites, but no cossyrite. No perlitic cracks are seen in these or any of the glassy groundmasses.

Chemical composition.—Four analyses by myself and four by Foerstner are given:

ANALYSES OF HYALOPANTELLERITE

(KHAGIARAL VARINGOSE-GRORUDOSE)

	A	B	C	D	E	F	G	H	As	Bs	Cs	Ds
SiO_2	69.91	66.07	69.33	67.85	69.61	68.75	68.33	67.89	1.165	1.101	1.156	1.131
Al_2O_3	8.58	11.74	8.62	12.87	8.02	5.91	10.94	11.53	.084	.115	.084	.126
Fe_2O_3	1.81	2.05	2.65	1.84	7.17	5.81	3.74	4.51	.011	.013	.017	.012
FeO	5.86	5.88	5.52	4.54	2.83	5.33	5.41	4.52	.082	.082	.076	.063
MgO	0.28	0.13	0.52	0.30	0.65	0.08	0.16	0.62	.007	.003	.013	.008
CaO	0.33	0.46	0.52	0.17	0.88	2.11	1.36	1.51	.006	.008	.009	.003
Na_2O	6.41	6.89	4.78	6.03	7.47	7.52	7.09	5.79	.103	.111	.077	.097
K_2O	4.71	4.80	4.71	4.83	2.88	4.28	4.08	3.71	.050	.051	.050	.051
H_2O+	0.22	0.43	2.35	0.13	0.74	n.d.	n.d.	0.33	....	....	....	....
H_2O-	0.13	0.03	0.27	0.02	n.d.	n.d.	n.d.	....	....	....	....	....
TiO_2	0.75	0.92	0.85	0.83	n.d.	n.d.	n.d.	n.d.	.009	.012	.011	.010
ZrO_2	....	0.12	....	....	....	....	....	....	....	....	....	....
P_2O_5	0.16	0.18	....	0.08	n.d.	n.d.	n.d.	n.d.	.001	.001	....	.001
SO_3	....	0.23	....	....	....	....	....	....	....	....	....	....
MnO	0.24	0.16	0.27	n.d.	n.d.	n.d.	n.d.	n.d.	.003	.002	.004	....
BaO	....	none	....	...	....	....	CuO= 0.25		....	....	....	....
	99.39	100.09	100.39	99.49	100.25	100.02	101.36	100.41	....	....	....	....

A. Gelkhamar. H. S. Washington, analyst.
B. Khagiar. H. S. Washington, analyst.
C. Cantina Ziton. H. S. Washington, analyst.
D. Obsidian. Costa Zeneti. H. S. Washington, analyst.
E. Khagiar. H. Foerstner, analyst. *Zeits. Kryst.*, VIII (1884), 173.
F. Cuddia Randazzo. H. Foerstner, analyst. *Zeits. Kryst.*, VIII (1884), 179.
G. Khania. H. Foerstner, analyst. *Zeits. Kryst.*, VIII (1884), 170.
H. Monte Sant' Elmo. H. Foerstner, analyst. *Zeits. Kryst.*, VIII (1884), 186.
As. Mol numbers of A. Bs. Mol numbers of B.
Cs. Mol. numbers of C. Ds. Mol numbers of D.

These analyses resemble those of the preceding type in most respects, but differ in the higher soda and in the relative amounts of the iron oxides, ferrous oxide being here largely in excess of ferric, both in percentage and molecularly, though the sums of the two in both types remain about the same. Foerstner's analyses show the same relations to mine as in the previous cases, a tendency to lower alumina, and higher ferric oxide, magnesia, lime, and soda. Except in E his ferrous oxides are higher than ferric, or nearly so. I could detect none of the copper noted by him in any of my rocks.

Norms.—The norms of my analyses are as follows:

	A	B	C	D
Q	28.38	14.70	28.02	15.36
Or	27.80	28.36	27.80	28.36
Ab	17.82	33.54	17.82	39.30
Ac	5.08	6.01	7.85	5.54
Ns	7.08	4.15	3.17	1.22
Di	0.75	1.24	2.16	....
Hy	10.34	9.01	9.28	7.80
Il	1.37	1.82	1.67	1.52
Ap	0.34	0.34	....	0.34
	98.96	99.17	97.77	99.44
Rest	0.35	0.81	2.62	0.15
	99.31	99.98	100.39	99.59

These norms are noteworthy because of the large excess of soda, expressed as sodium metasilicate, over alumina and ferric oxide, which they show. This finds expression modally in the presence of cossyrite, and study of the thin sections shows that, in a general way, the amount of cossyrite present is correlated with that of sodium metasilicate in the norm. The analysis of cossyrite by Dittrich[1] yields nearly 9 per cent of sodium metasilicate, and it is also very high in ferrous oxide. These two factors determine the chief chemical differences between the two main types of pantellerite—the one with dominant aegirite and the other with dominant cossyrite among the mafic minerals.

These norms show that all the rocks are in dosalane. The Gelkhamar and Cantina Ziton rocks fall in varingose, transitional

[1] Cf. J. Soellner, *Zeits. Kryst.*, XLVI (1909), 539.

to grorudose, and the subrang is almost dopotassic through the very small amount of alumina present, II.3(4).1.(2)3. As this dopotassic subrang is as yet unknown, they may best be called grorudose-varingose. The others fall centrally in grorudose, II.4.1.3.

It will have been noted that none of the pantellerites analyzed by me fall in the subrang pantellerose, II. 4.1.4. This name was chosen for the subrang because of two analyses by Foerstner, which were then the only ones available.[1] As we shall see, however, these must be considered to be incorrect, and this case may serve as an example of the danger of basing rock names depending on chemical characters on any but reliable analyses. Further examples will be found in a forthcoming second edition of my *Collection of Rock Analyses*.

Mode.—The rock is so dominantly hyaline that the mode is indeterminate. It may be of interest to note, however, that if the lava had wholly crystallized the rocks would have had about the following composition: quartz 15 to 25, soda-microcline 45 to 55, cossyrite 15 to 25, aegirite or aegirite-augite 5 to 10. It is evident that a large proportion of the aegirite and cossyrite molecules would have been among the last to crystallize out. J. Soellner,[2] through an analysis by Dittrich, has shown that the olivine from this type of pantellerite is an almost pure fayalite, with FeO: MgO = 10:1. The analysis and the norm of the olivine-bearing pantellerite C confirm this, the ratio being 6:1.

It seems to be preferable to use the name hyalopantellerite for this type rather than to coin a new name. If the latter be deemed advisable that of *khagiarite* might be suggested.

BASALT (CAMPTONOSE)

Occurrence.—Basalts, all of which belong to the subrang camptonose (III. 5.3.4), are found only in the northwest corner of the island, being the products of eruption of the last phase of the volcano. They poured out from small cones—Cuddie Ferle, Bruciate, Monti, Rossi, Nera, and through the pantellerite on the

[1] Cf. H. S. Washington, *Prof. Paper U.S.G.S. 14*, 1903, p. 221.

[2] J. Soellner, *Zeits. Kryst.*, XLIX (1911), 144.

north slope of Monte Sant' Elmo—forming rather extensive flows from 2 to 5 meters thick, and accompanied by much scoria and ash. There are a few basaltic dikes cutting yellow pantellerite tuffs but these are of small size.

Megascopic characters.—These basalts present no unusual features and are of the common type, dark-gray to black rocks, aphanitic or nearly so, with few small phenocrysts of dark-green augite and sometimes yellow olivine and fewer of feldspar. Most of the specimens are slightly vesicular and scoriaceous *aa* flows are common. The scorias are generally black, but sometimes reddish. About Cuddia Ferle small, ovoidal or fusiform bombs are found.

Microscopic characters (*Figs. 10 and 11*).—The phenocrysts of feldspar are anhedral and either stoutly prismatic or tabular, parallel to *b* (010). Nearly all of them are of labradorite, about Ab_1An_1, with the usual twinning lamellae, and a few show a border of more sodic material. There are some phenocrysts of soda-microcline, especially in lava from Cuddia Ferle, which carry few inclusions, mostly of glass. Subhedra of colorless augite, often in clusters, are fairly common. Olivine phenocrysts are rather more common than those of augite in the Ferle basalt, but olivine is wanting in that from Sant' Elmo. It is highly euhedral, very fresh, with few inclusions of magnetite. The rock analysis and norm show that it is an olivine and not fayalite.

The groundmass is typically basaltic, composed largely of thin plates of labradorite, grains of colorless augite, and considerable magnetite. In the larger flows it is holocrystalline. No nephelite is to be found.

A dike of basalt which cuts the yellow pantellerite tuffs at the northeast end of Costa Zeneti merits a few words of description. It has an east-west trend, approximately radial toward Cuddia Ferle, which is about one and a half kilometers to the west. It is vertical, from 10 to 30 cm. wide, and has hardened and blackened the rather incoherent tuff for about 5 cm. on either side. The rock itself is jet black and aphanitic, very minutely vesicular, more coarsely so toward the borders, and is almost free from phenocrysts, very small (1–2 mm.) feldspars being sparingly present. In the section thin tables of labradorite are prominent, augite

FIG. 10.—Basalt, Cuddia Ferle. × 20

FIG. 11.—Basalt, dike, Costa Zeneti. × 20

anhedra are not common and there is very little olivine. These lie in a base of glass which, black under low powers, is seen under high to be thickly crowded with brown and black globulites. In this respect, as well as in the character of the feldspars, it is much like the basalts of the submarine eruptions of 1831 and 1891,[1] which it also resembles chemically.

Chemical composition.—Three analyses of these basalts, with two of the submarine lavas, and two by Foerstner, are given in the table.

ANALYSES OF BASALT

(CAMPTONOSE)

	A	B	C	D	E	F	G	*Aα*	*Bα*	*Cα*
SiO_2	46.40	46.22	45.72	44.83	48.97	49.87	49.35	0.773	0.770	0.762
Al_2O_3	14.34	12.23	12.45	11.73	16.37	14.80	15.71	.141	.120	.122
Fe_2O_3	4.09	4.91	1.57	1.35	1.33	8.25	7.44	.026	.031	.010
FeO	8.22	7.71	12.01	11.79	8.56	6.88	6.96	.114	.107	.167
MgO	7.00	6.74	5.29	5.50	6.22	6.77	5.71	.175	.169	.132
CaO	9.85	9.86	9.58	9.63	7.49	9.36	9.80	.177	.176	.171
Na_2O	3.59	3.39	3.40	3.34	4.09	2.81	2.96	.058	.055	.055
K_2O	1.00	1.13	1.08	1.40	1.72	0.68	1.31	.011	.012	.011
H_2O+	0.14	0.17	0.40	0.81	0.38	0.45	0.49	....	....	....
H_2O-	0.08	0.05	0.01	0.10	0.08	n.d.	n.d.	....	....	....
TiO_2	4.54	5.68	6.43	6.88	3.95	n.d.	n.d.	.057	.071	.080
ZrO_2	none	....	....	....	....	....	....	....	....	....
P_2O_5	0.85	1.46	1.54	2.14	1.04	n.d.	n.d.	.006	0.010	.010
SO_3	0.12	....	....	....	....	....	....	....	....	....
MnO	0.25	....	0.16	0.20	0.06	n.d.	n.d.	0.003	....	0.002
NiO	....	....	0.15	....	0.08	....	....	....	....	....
BaO	0.09	....	....	....	....	....	....	....	....	....
SrO	0.03	....	0.03	....	....	....	....	....	....	....
	100.59	99.55	99.82	99.70	100.34	99.87	99.73	....	....	....

A. Cuddia Ferle. H. S. Washington, analyst.
B. Monte Sant' Elmo. H. S. Washington, *Q.J.G.S.*, LXIII (1907), 74.
C. Dike, Costa Zeneti. H. S. Washington, *Q.J.G.S.*, LXIII (1907), 74.
D Foerstner Volcano (1891). H. S. Washington, *Am. Jour. Sci.*, XXVII (1909), 145.
E. Graham Island (1831). H. S. Washington, *Am. Jour. Sci.*, XXVII (1909), 138.
F. San Marco. H. Foerstner, analyst. *T.M.P.M.*, V (1884), 393.
G. Cuddie Monti. H. Foerstner, analyst. *T.M.P.M.*, V (1884), 393.
Aα, *Bα*, *Cα*. Mol. numbers of A, B, and C, respectively.

The analyses of the Pantellerian basalts are much alike, and except for the rather low silica and high titanium and phosphorus, are not specially noteworthy. The only marked difference is in the iron oxides. While the sum of both is about the same in all, in

[1] H. S. Washington, *Am. Jour. Sci.*, XXVII (1909), 131.

the flows A and B the molecular amount of FeO is about four times that of Fe_2O_3, but in the dike C it is seventeen. In this respect the dike basalt resembles the basalts of the two submarine eruptions D and E, the former close to the harbor of Pantelleria and the latter about 33 miles to the northeast. It will be seen that C and D are almost duplicates, while E differs considerably in the silica and other respects. These relations of the iron oxides give rise to the idea that the ferrous oxide has been prevented from oxidation in the dike and the submarine eruptions—a point which has been discussed in a previous paper.

Norms.—The norms of the Pantelleria basalts are as follows, those of the submarine ones having been given in the paper cited:

	A	B	C
Or	6.12	6.67	6.12
Ab	28.30	28.82	28.82
An	20.02	14.73	15.57
Ne	1.14	.....	.....
Di	18.81	19.54	18.77
Hy	.....	8.06	5.74
Ol	9.32	0.28	6.29
Mt	6.03	7.19	2.32
Il	8.66	10.79	12.16
Ap	2.02	3.36	3.36
Rest	0.46	0.22	0.69
	100.88	99.66	99.80

These norms place all three Pantellerian basalts in camptonose, III. 5.3.4, a subrang in which many basalts and gabbros fall. It will be noted that, in spite of the low silica, nephelite is not present in the norm, except to a slight extent in the Ferle rock, and it can hardly be said that these basalts have the trachydoleritic character assigned them by Rosenbusch (p. 1357). It will also be observed that these norms correspond with the microscopic characters, the Ferle rock carrying considerable olivine, which is wholly absent from the Sant' Elmo basalt.

Mode.—It is impracticable to estimate the mode by Rosiwal's method because of the fineness of the grain. Apart, however, from the small amount of alumina (to be taken from normative anorthite) which enters the augite the mode is essentially norma-

tive, and the modes of the two basalts of Ferle and Sant' Elmo may be roughly stated as follows, the orthoclase being reckoned in with albite. It is possible that the nephelite molecule of the norm exists as carnegieite in the feldspar.

	I		II
Ab_1An_1	50	Ab_3An_2	48
Nephelite	1	Augite	32
Augite	22	Ores	17
Olivine	9	Apatite	3
Ores	14		100
Apatite	2		
	100		

A STUDY IN THE PETROLOGY OF SEDIMENTARY ROCKS[1]

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INTRODUCTION

Since the introduction of the petrographic microscope about the middle of the last century a great mass of detailed information concerning the composition of rocks has been accumulated, but by far the greater part of this concerns igneous rocks alone. Metamorphic rocks have received their due share of attention, but sedimentary rocks have been almost entirely neglected. Thus, most university courses in petrology touch on the last-named class only in a more or less perfunctory way, and similarly in practical work the geologist generally confines the use of his microscope chiefly or entirely to the igneous rocks. This disparity is the more notable because of the fact that sedimentary rocks preponderate at the earth's surface, and while the study of their petrology does not seem to possess the fascination which attracts the students of igneous rocks, their areal importance is certainly such as to command attention. This paper is a preliminary and more or less tentative discussion of the value of microscopic work in the correlation of stratified rocks, with an example of an application recently made by the writer. Mr. D. F. Hewett, of the United States Geological Survey, has been working along similar lines, and the writer takes this opportunity of expressing his appreciation of Mr. Hewett's many valuable suggestions.

Sediments, by their very nature and the manner of their derivation, do not lend themselves readily to the taxonomic principles which we apply to igneous rocks, nor can their almost infinite variations be traced and interpreted as clearly. It is perhaps for this latter reason that geologists have in general been content to classify a rock as sandstone, or shale, or arkose, without attempting

[1] Published by permission of the Director of the U.S. Geological Survey.

to inquire very closely into the proportions of its component minerals or the shape of their grains. Many sedimentary rocks, it is true, have been examined and described as lithologic types for educational purposes,[1] or because of some peculiarity in distribution or occurrence,[2] and there are a few instances in which they have been carefully studied for economic reasons,[3] but little work of a genetic character, directed upon the rock as part of a mass or formation rather than as a more or less fortuitous rock type, has been done.

THE IMPORTANT LINES OF RESEARCH ON SEDIMENTARY ROCKS

During the past decade attention has been directed to sedimentary rocks by the masterly studies of Johannes Walther in Germany and the amplification of his work in this country by Barrell, Grabau, and others. These geologists have, however, dealt almost entirely with the stratigraphic relations of the beds, and such structural features as cross-bedding, mud cracks, etc. In endeavoring to ascertain the manner of deposition of the rock, whether for example as a deep-sea deposit or a river sediment, a delta or playa lake, they have assigned somewhat minor importance to its petrology, considering chiefly its broader megascopic characters. Considerable work has also been done upon the transportation of sedimentary material by water and by wind[4], and the consideration of criteria by which the amount of such movement may be estimated. Thus W. H. Scherzer[5] has constructed a classification of sand grains based largely on their size, their degree of angularity and the amount of

[1] Such descriptions are given by Diller, *Bull. U.S. Geol. Survey No. 150*, 1898; by Harker, *Petrology for Students;* by Kemp, *Handbook of Rocks;* by Hatch and Rastall, *Petrology of the Sedimentary Rocks;* and by the authors of most of the other textbooks on lithology.

[2] See for example L. Cayeux, "Structure et classification des Gres et Quartzites," *Congres geol. internat. C.R.*, 10th Session, 1906, pp. 1211–22.

[3] See for example, C. B. Berkey, *Bull. New York State Mus., No. 146*, 1911, pp. 124–48.

[4] See for a summary, with very complete lists of references, E. E. Free, "The Movement of Soil Material by the Wind," *Bull. Bureau of Soils, U.S. Dept. Agric., No. 68*, 1911.

[5] "Recognition and Classification of Sand Grains," *Bull. Geol. Soc. Amer.* (XXI), 1910, 625–62.

their polish. Finally, while relatively little detailed study of the mineral composition has been made, we have a fairly definite idea of the minerals which commonly make up clastic rocks, and, in the case of feldspar at least, some conception of its genetic significance.

It is the belief of the writer that the three lines of research mentioned in the preceding paragraph, viz., upon the broad structural features, the shape of the grains, and the mineral character of the grains, may profitably be combined, and that the value of the results obtained by any one is greatly enhanced when considered in relation to the other two. The importance of a close study of the structural features of a clastic rock has been amply demonstrated by Barrell and others. The criteria given by Scherzer, when it is possible to apply them, are of similar value in determining the manner of deposition of the sediment and something of its history prior to deposition. Finally, the mineralogical composition of the rock, though in many cases having no apparent significance, is in others decidedly important. When a sandstone is made up practically entirely of quartz, as is the St. Peter sandstone, the significance of this fact is immediately recognized and taken into account in considering its history and derivation.[1] Thus, C. P. Berkey considers the St. Peter sandstone of eolian (sand dune) origin, because of the fact that it contains 98 to 99 per cent of quartz, largely in rounded grains of a nearly uniform size. Certain formations in the east, such as the Newark group, have been assigned a continental origin partly because of their arkosic character and red color, and this also illustrates a partial application of these principles. When the composition is less apparent to the naked eye, however, the importance of its determination may not be so evident; and very little is known of the exact mineral constituents of the great thickness of Cretaceous and Tertiary strata in the Great Plains and Rocky Mountain provinces.

Aside from the importance of such data in determining the history and origin of a rock they may in some cases have a distinct correlative value. Thus, in the instance of the Lebo shale member of the Fort Union formation described below, the writer was able to

[1] See "Paleogeography of St. Peter Time," *Bull. Geol. Soc. Amer.*, XVII (1906), 229–50.

correlate the strata by the varying, though generally small, amount of andesitic tuff or ash which it contains, the Lebo member at the type locality consisting chiefly of andesitic material. Similarly if a formation, or some particular stratum of a formation, were known to contain tourmaline, or a large amount of mica, or spherulitic glass, or some other distinctive constituent, this information might prove a valuable auxiliary in correlation to stratigraphic and paleontologic evidence. Though the instances last cited are doubtless uncommon it is probable that ash is rather widely distributed through the Cretaceous and Tertiary rocks of the west, and it may prove to be an aid to correlation in many cases. Moreover, even where conditions are not favorable to using the petrology in this way it is possible that it may throw light on the exact position of a doubtful formation boundary. Thus, D. E. Winchester, United States Geological Survey, believes that evidence of this kind may lead to fixing the lower limit of the Mesaverde formation in the Zuni Indian Reservation, New Mexico, where by reason of a lack of diagnostic fossils at the critical horizon the exact base of the formation cannot be otherwise located. The case of the Lebo shale described below furnishes a simple example of the value which petrologic evidence may have.

THE LEBO SHALE MEMBER OF THE FORT UNION FORMATION IN EASTERN MONTANA

General statement.—During the summer of 1911 the writer examined for the United States Geological Survey an area in eastern Montana known as the Little Sheep Mountain coal field[1] which extends about 60 miles westward from the town of Terry, on the Yellowstone River. In contiguous areas on the east and south the strata had been mapped as Fort Union and Lance.

About 850 feet of the upper or yellow strata of the Fort Union formation are exposed in the Little Sheep Mountain field, the age of these rocks being definitely established by paleontological evidence. The beds are made up of sandstone, sandy shale, and clay shale, generally soft and in many places incoherent, and commonly yellow

[1] G. S. Rogers, "Little Sheep Mountain Coal Field," *Bull. U.S. Geol. Survey No. 531*, 1913 (in press).

in color. The areas in which these beds are exposed are gently rolling prairies, or less commonly hills, with bare slopes. Directly across the river from Terry the yellow beds of the Fort Union formation are underlain by the Lance formation, of which only about 150 feet are exposed. This formation resembles the Fort Union in every way, except that there are perhaps more beds which are light gray in color instead of yellow. The contact between the two formations is marked by a coal bed (known as bed U) which is persistent through the eastern part of the field.

At a point about five miles west of Terry, however, the strata for 200 feet above coal bed U are dark gray in color and strikingly dissimilar to both the yellow Fort Union and the Lance (see Fig. 1). This dark gray member is composed of very irregularly deposited masses of shale with occasional arkose sandstones. Except for the numerous irregular and discontinuous layers of hard ferruginous concretions, and for a few fairly hard and generally massive sandstones, the beds are always soft and practically incoherent. The outcrop of this member, which traverses in a broad belt the entire field west of this locality, is characterized by the formation of badlands so rough in many places as to be almost impassable. This land is given over largely to grazing purposes, and even in the comparatively level creek bottoms it is very poor for agricultural purposes. The general sterility of this member, its tendency to form badlands, and its decidedly dark gray color all combine therefore to make it easily identifiable in the field.

For the reasons given below this mass of dark shale is believed to represent the Lebo shale member of the Fort Union formation. The Lebo was first described on Lebo creek in the vicinity of the Crazy Mountains,[1] about 175 miles west of the Little Sheep Mountain field. It is there interpreted as an outfingering of the Livingston formation,[2] which is composed of andesitic material, both detrital and tuffaceous, and which covers considerable areas west and south of the Crazy Mountains. This intercalated fan extends

[1] R. W. Stone and W. R. Calvert, "Stratigraphic Relations of the Livingston Formation of Montana," *Econ. Geology*, V, No. 6, September, 1910, p. 752 ff.

[2] See W. H. Weed, "The Laramie and the Overlying Livingston Formation in Montana," *Bull. U.S. Geol. Survey, No. 105*, 1893.

east to the Bull Mountains, about 50 miles west of the area under discussion, where it was mapped by C. T. Lupton.[1] Between this area and the Little Sheep Mountain field the beds are raised in a gentle anticline which exposes the Pierre shale, and the Fort Union and Lance are eroded, so that there is no way of actually tracing the Lebo member from the one field to the other.

Stratigraphic relations and structural features of the Lebo shale member.—The distinctive appearance of this member facilitated the recognition of the fact that it is wedge or fan-shaped. In the eastern part of T. 12 N., R. 51 E., directly opposite Terry, it is lacking. Coal bed U, which is taken as marking its base, is here

FIG. 1.—View of badlands in T. 12 N., R. 50 E., P.M., Montana, looking north; and showing the yellow beds of the Fort Union formation in the background overlying the gray Lebo shale member.

directly overlain by the yellow beds of the Fort Union and underlain by the light yellowish gray beds of the Lance. In the northeast quarter of sec. 9, T. 12 N., R. 51 E., there are about 12 feet of dark-gray shale above this coal bed. A half-mile to the west the strata above it are yellow and gray, alternating in about equal quantity; a mile farther west there are 200 feet or more of dark-gray material above it with only occasional beds of dirty yellow (see Fig. 1). In sec. 29 of T. 11 N., R. 50 E., seven miles southwest of the

[1] C. T. Lupton, "The Eastern Part of the Bull Mountain Field, Montana," *Bull. U.S. Geol. Survey, No. 431*, 1909, pp. 163–89.

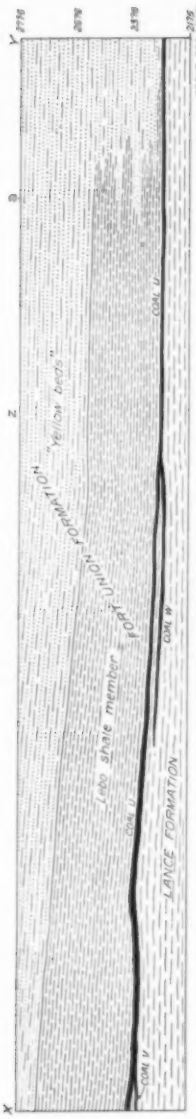

FIG. 2.—Diagram showing stratigraphic relations of Lebo shale member of Fort Union formation in Little Sheep Mountain coal field. Compiled from sections made along a line running 11 miles northeast from the mouth of Custer Creek (point *X*) to point *Z*; thence six miles east to a point opposite Terry (point *Y*). At point *a* a detailed section was made which showed the alternation of yellow and dark-gray strata as indicated.

last mentioned locality there are 250 feet of these dark shales between coal U and the yellow phase of the Fort Union; and on Custer Creek, seven miles farther southwest, about 340 feet. Beyond this there was no opportunity for measurement, and 20 miles farther west the coal which marks the base of the Lebo runs out of the district. The Lebo is therefore fan-shaped (see Fig. 2), of a thickness unknown in the western part of the field, but probably not greater than 350 or 400 feet; and reaching its eastern limit in this area in sec. 11, T. 12 N., R. 51 E., opposite Terry.

A noticeable structural feature of the Lebo member is the very irregular character of the beds, which change rapidly in a horizontal direction. A measured stratigraphic section represents the strata in one place only; at a distance of 1,000 feet on either side many of the beds change in color and often in texture. Scattered throughout the member are numerous lenses of a white and sandy material; these are commonly less than 2,000 feet in length and perhaps 60 feet in thickness, and are often only 200 feet long and 10 or 20 feet thick. In many cases they lie obliquely to the surrounding beds (Fig. 3) and are themselves strikingly cross-bedded (Fig. 4). The latter feature, together with

ripple-marks and mud cracks, is very common throughout the whole of the Lebo. The lenticular and irregular character of these strata extends to their coals as well, which are generally dirty, and, with the exception of bed U, of no great extent.

Petrologic evidence—mineralogical composition and character of grains.—The Lebo shale on the northeastern flank of the Crazy Mountains is described as a derivative of an andesite. Microscopic examination showed that certain facies are nearly pure tuffs, but that generally a considerable amount of plagioclase is present and

FIG. 3.—View in badlands on Custer Creek showing irregular character of the Lebo shale sediments, and the intercalation of lenses of white sandy clay which contains about 50 per cent andesitic ash, sec. 11, T. 11 N., R. 49 E., P.M., Montana.

that the whole is set in a fine chloritic groundmass. Fragments of hornblende and augite are also frequently found, and in places there is a considerable admixture of quartz. Eight thin sections were made of the more coherent members of the dark shale of the district discussed in this paper and in addition a number of sections of incoherent material were prepared without grinding; and all these were examined by the writer. Two of the thin sections were fine-grained dark gray shale, so fine in fact that the microscope revealed no recognizable grains. They seem to consist of kaolin stained

brown by iron oxide, and the shale may have been derived from nearly any kind of an igneous rock. Three of the sections were made from the grayish sandy lenticular material mentioned above, collected at two places about 10 miles apart in T. 9 N., Rs. 42 and 43 E. They are all decidedly tuffaceous in character and contain about 50 per cent of angular, subangular and rounded fragments of a brown volcanic glass, commonly more or less devitrified and altered. Quartz in small angular grains makes up about 40 per cent, and the remainder consists chiefly of kaolin and chlorite.

FIG. 4.—Cross-bedding in white sandy clay facies of the Lebo shale member, sec. 30, T. 11 N., R. 49 E., P.M., Montana.

Though the quartz indicates a considerable admixture of foreign material, this would be expected at a distance of 175 miles from the supposed source. One slide was made from a fine-grained, sandy, yellow-gray bed; this also revealed the presence of some volcanic glass, but the rock consisted chiefly of very small fragments of chloritic material with considerable quartz. Finally two sections of sandy shale partially baked by the action of a burning coal bed were examined. Their original character was, of course, largely destroyed, but fragments of a fresh green augite were identified in both of them. These descriptions hold also for the slides prepared

from the incoherent material; several were too fine-grained to permit of satisfactory identification, but the remainder contained varying quantities of glass, commonly badly altered. The sandy white material is thus derived directly from andesitic effusive material; all of the other rocks examined which were coarse enough to allow of study indicate a derivation, in large part at least, from a basic igneous rock; the shale is in general too fine to warrant an opinion as to its origin, but its evidence is not adverse. Furthermore, specimens of the yellow Fort Union above and of the Lance below were examined and all indicate a probable derivation from a much more siliceous rock; at least it may be said that they differ decidedly from the dark shale.

Owing to the fact that most of the important constituents of these rocks—glass and ferro-magnesian minerals—are prone to comparatively rapid alteration the evidence as to the shape of the grains in this instance cannot be satisfactorily obtained. The feldspar grains are in general nearly or quite fresh and are angular. The quartz is commonly in decidedly angular grains and only a few were noticed which were subangular or rounded. Similarly in the case of the glass it seems that the fresher the grain the more angular it is, some being found which were fairly fresh and distinctly angular. While these rocks are not favorable for a detailed study of the shape of the grains it may be said that they show the complete assortment as to size which characterizes Scherzer's aqueous type, but with the angularity which is regarded as diagnostic of the volcanic, glacial and residual types. Taking the mineral composition into account therefore they may be classified as aqueo-volcanic rocks.

Interpretation.—Because of this concurrence of the stratigraphic and petrologic evidence therefore it seems proper to correlate these strata with the Lebo member. According to this hypothesis a large part of the material has been transported from the Crazy Mountains, although a considerable increment of foreign detritus has been received along the route. The striking cross-bedding and the decided lenticularity and lack of persistence of the beds argue for a fluvial origin, while the angularity of the grains themselves and their assortment as to size offer a similar suggestion and preclude the possibility of any long eolian transportation. It is possible that the

lenses of the white sandy tuffaceous material described above may represent the ancient stream courses. These lenses are numerous and generally of small size; in many cases they lie at a small angle across the strata and are themselves always strikingly cross-bedded (see Figs. 3 and 4). It would not be expected that recent erosion of the badland type would lay bare an old river course with its meanders for any great distance; the recent gulleys would cut across at all angles and the exposures of the old alluvium would pinch out abruptly. The shorter lenses would then represent an approximate cross-section of the old channel, while the longer ones might be interpreted as more or less complete approaches to a longitudinal section.

APPLICABILITY OF THESE PRINCIPLES

Lack of exactness in our present knowledge.—The application of the principles above outlined is naturally limited to certain formations, and is at the present time hampered by our comparatively small knowledge of the petrology of clastic rocks. The lack of detailed microscopic study is making itself felt in the deplorable looseness of our definitions of the types. A committee on the nomenclature of the more common types of sedimentary rocks was recently appointed in the United States Geological Survey, and in the course of a rather exhaustive search through the literature in an endeavor to find some basis for standardizing and delimiting the types in common use encountered a surprising discordance of opinion. Shale, clay, graywacke, arkose, argillite, etc., are differently defined in different books and in some cases not defined at all. With so little literature on the exact composition of sedimentary rocks and with the very basis of the lithology of these rocks in this condition it is difficult to say how great an aid microscopic work will prove in solving the problems of correlation or in reconstructing the conditions under which a sediment was laid down. At the present time it would seem that in many, if not most cases, such a study would have no immediate and practical value, but on the other hand, there are certainly many problems in which it might be used with direct advantage, as in the instance given above.

The lack of exactness in our present knowledge may be further illustrated by the following example, which represents another and

somewhat different application of these principles. The writer in the course of an examination of a portion of the ceded lands of the Crow Indian Reservation, Montana, during the past summer, followed the outcrop of a coal bed in the Lance formation for a distance of about thirty miles; and throughout this distance the bed contains a parting of material which closely resembles a brown carbonaceous sandstone. This parting varies only from three-fourths of an inch to $1\frac{1}{4}$ inches in thickness, and its constancy and persistence proved a decided aid in recognizing and correlating the coal bed. Such characters are exceptional in the Tertiary and Cretaceous continental deposits of the west, and the writer was prompted therefore to examine microscopically several specimens of the parting. In thin section this material proved to be, not a clastic sandstone as supposed, but to be a nearly pure aggregate of delicate mineral crystals, which undoubtedly formed *in situ*. The optical characters correspond to those of Leverrierite.[1] The mineral is now being more carefully examined and analyzed and the writer hopes to discuss it in a later paper.

It is apparent of course in this instance that the practical value of the small layer did not depend on microscopic examination, since use was made of it in correlation before its real nature was known. Microscopic study in this case merely served to explain its persistency and homegeneity, the characters which rendered it of value in the field, and to throw light on its origin and its relation to the coal bed and other strata. Moreover, the formation of such a pure mineral deposit in the midst of a heterogeneous mass of largely continental sediments is certainly of scientific interest; and if it is, as the writer is inclined to believe, not an uncommon development, but merely one which lack of previous petrologic work has held us in ignorance of, its bearing on the accumulation and alteration of sedimentary rocks is manifestly important.

Practical difficulties.—The microscopic study of sedimentary rocks is attended by certain practical difficulties which the writer can attempt only to suggest. In the first place the fineness of the material and the extent of its decomposition are important obstacles to the study of shale. Where the grain is not too uniformly small,

[1] First fully described by P. Termier, *Ann. d. Mines*, XVII (1890), 272.

washing or floatation may be used, thus removing the finely divided and thoroughly hydrated—perhaps colloidal—material. If more elaborate methods are desired, recourse may be had to the elutriator, the electro-magnet, heavy liquids, etc.[1] These methods of course destroy the proportions of the constituents, but facilitate the study of the features—assortment, angularity, and polish,—which are really important to the consideration of the rock from a genetic standpoint, and they will in many cases be the most expedient. On the other hand it seems probable that certain very fine-grained shales and clays are largely made up of colloidal material, which may prove to be homogeneous in composition and to have more or less distinct optical properties, and in such cases it may be desirable to study it as a whole without attempting at first to ascertain the character of the mineral particles from which it was derived.

Secondly, the question of field criteria for recognizing the particular rocks likely to prove critical presents itself, since it is obviously impossible to make and examine a complete collection of all the variations in a series. It is patent, of course, that very fine-grained rocks, since they do not respond satisfactorily to our present elementary methods of study, are less likely to prove helpful than the coarser-grained varieties; and on the other hand that the presence of uncommon constituents in very coarse sandstones and conglomerates can usually be recognized without the microscope. The writer must confess his inability to suggest any definite rule, however, and believes that from the nature of the case none can be framed. Such a question must be left largely to the field geologist.

Finally, it seems desirable that the geologist who studies the rocks in the field should be the one to examine them microscopically. The petrology of a sedimentary rock is in most cases of little or no significance except when considered in relation to the structural and stratigraphic features. Furthermore, its exact horizon is generally important and the relation of the stratum to those adjoining; and such data will, of course, be noted by the collector in any case.

[1] See F. H. Hatch and R. H. Rastall, *Petrology of the Sedimentary Rocks*, 1913, Appendix on the Systematic Examination of Loose Detrital Sediments, by T. Crook.

There are many minor points, however, which the field geologist remembers, but which were considered of too small importance to write down at the time, and which may yet derive an unexpected significance from the results of a simple petrologic study. When possible therefore, it is advantageous for the field man to examine his own material.

SUMMARY AND CONCLUSIONS

The amount of petrologic work done on sedimentary rocks, especially the more or less incoherent Cretaceous and Tertiary rocks of the West has been comparatively small, and most of the study made has been directed toward the rock as a rock type, rather than as a part of the rock mass or formation. Of late years attention has been directed to the broader structural features of clastic rocks and much information concerning the manner of deposition has been accumulated. It is believed that petrologic study of the mineral constitutents and the character of their grains will prove an important aid in determining the history of the rock, and that such study may also lead to facts of value in correlation and in the fixing of formation boundaries. An area of dark-gray shale near Terry, Montana, was correlated with the Lebo shale in the Bull Mountains to the west, largely by petrologic evidence. In this particular instance the determining constituent was andesitic ash, but in other cases the presence of other more or less distinctive constituents may be found significant and of value in correlation. There are two apparent difficulties confronting a study of this kind: first, those arising from the fact that many sedimentary rocks are made up of badly altered minerals occurring in grains too small for satisfactory examination; and second, the difficulty of choosing the proper rocks for detailed study. The fact that our definitions of sedimentary rock types are very vague and loose is in itself an argument for more petrologic study; and while it is not probable that this work will be found to have a very broad application to correlation, as in the one instance described, it still seems that it may prove an important auxiliary in that direction to the other lines of research at our command, and will in addition shed valuable light on the history of the rock.

ON THE RELATIONSHIP OF THE SOUTH AFRICAN PERMIAN REPTILES TO THOSE OF RUSSIA

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Professor Williston[1] has lately issued a paper entitled "Primitive Reptiles: A Review" in which he sums up the present state of our knowledge of the American Permian reptiles. More briefly he discusses the Permian reptiles of Europe; and has some references to the South African types. Williston deals only with the lower Permian reptiles, and as we know only very few reptiles from the lower Permian rocks of South Africa the references to our African types are brief. As, however, possibly he or some other will later be discussing Permian reptiles in general, some new facts which I wish to state will probably be welcomed. Williston is inclined to regard our Karroo beds which contain *Pareiasaurus* as Upper Permian, since the *Pareiasaurus* beds of North Russia are undoubtedly Upper Permian. In this I think he is incorrect.

In the Karroo we have a continuous series of shales and sandstones from the Droyha conglomerate which we may regard as basal Permian up to the Molteno beds which we know to be Rhaetic. Thus we have the whole Permian and Triassic periods represented by about 9,500 feet of strata. The whole thickness we can subdivide into zones as follows:

Burghersdorp beds	2,000 ft.
Lystrosaurus and *Procolophon* zone	2,000 ft.
Cistecephalus zone	1,000 ft.
Endothiodon zone	1,000 ft.
Pareiasaurus zone	1,000 ft.
Ecca beds	2,000 ft.
Droyha shales	500 ft.

[1] S. W. Williston, "Primitive Reptiles: A Review," *Journal of Morphology*, XXIII, No. 4, December, 1912.

The thicknesses of the various zones are only very approximate and vary considerably in different parts of the country. The Burghersdorp beds contain the following European genera *Trematosaurus*,[1] *Cyclotosaurus*, *Capitosaurus*, besides others allied to European Triassic forms and there can be no doubt that the beds are of Upper Triassic age. The *Lystrosaurus* and *Procolophon* zones may be regarded as corresponding to the Lower Triassic of Europe, though we have no genera corresponding to those of Europe.

All the zones from the *Cistecephalus* to the Droyha may be taken as representing the European Permian, and this is confirmed by the fact that the Russian "*Pareiasaurus*" zone corresponds, not with our *Pareiasaurus* zone, but with our *Cistecephalus* zone.

Anyone who is familiar with our typical South African *Pareiasaurus* and then looks at the Dwina Pareiasaurs will at once see that the resemblance is not striking; and had I found the Russian species at the Cape, I should have put it in a new genus probably. Just recently a new Pareiasaurian was discovered by Haughton in the *Cistecephalus* zone, and it has been described by Haughton and myself as a new genus, *Pareiasuchus peringaeyi*, and we have called attention to the fact that it resembles the Russian animals much more than does our older *Pareiasaurus*. But of much more importance than the doubtful *Pareiasaurus* is the Russian *Inostrausewia*. This is a huge carnivorous reptile something like our carnivorous types. But no known Therocephalians from our *Pareiasaurus* zone are the least like *Inostrausewia*.

Just recently we have got evidence that our Permian carnivora can be conveniently subdivided into two groups. The lower forms are the typical Therocephalians: the upper I am placing in a distinct group, the Gorgonopsia. It matters little whether this be regarded as a distinct family or suborder. I prefer to call it a distinct suborder. A paper is at present in the press dealing with the distinction of the groups. Though our small Gorgonopsian is known from the *Pareiasaurus* zone, it is in the *Cistecephalus* zone that the group becomes pre-eminent. A large South African type recently described as *Scymnognathus tigriceps* is possibly identical

[1] It is just possible *Trematosaurus* may be from the *Lystrosaurus* zone.

generically with *Inostrausewia*. Certainly it is closely allied, and certainly *Inostrausewia* is a Gorgonopsian.

If I were shown the Russian Dicynodonts and were told they had come from South Africa and were asked from what zone I thought they had come I should unhesitatingly say that they must come from the *Cistecephalus* zone. Nothing like them is known from any of the earlier zones and in the *Cistecephalus* zone we get Dicynodonts strikingly similar. I have therefore little hesitation in affirming that the Russian fauna of the Dwina is the fauna of our South African *Cistecephalus* zone, and this confirms the view I expressed eight years ago, that the *Cistecephalus* zone represents our most recent Permian beds and that our typical Pareiasaurs are Middle Permian. In the present state of our knowledge we may regard our Pareiasaurian genera distributed as follows:

Cistecephalus zone ..... *Pareiasuchus, Propappus*
Endothiodon zone ..... *Propappus, Anthodon*
Pareiasaurus zone ..... *Pareiasaurus*

SOME PARTLY DISSECTED PLAINS IN JO DAVIESS COUNTY, ILLINOIS[1]

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Jo Daviess County is the northwesternmost county in Illinois and adjoins northeastern Iowa and southwestern Wisconsin. The county is partly covered by the Galena and Elizabeth topographic sheets of the United States Geological Survey. The topography of this county occupying the southern part of the driftless area has remained unaltered by the ice invasion and is still exposed for physiographic study. The writer, in company with E. W. Shaw and B. H. Schockel, spent a large part of the field season of 1910 in Jo Daviess County in co-operative work between the United States Geological Survey and the Illinois Geological Survey, and the following paper is one result of that work.

Rock formations appearing at the surface in the district are of Ordovician and Silurian age, and are classified as follows:

Name of Formation	Kind of Rock	Thickness
Niagara	Dolomite	140 feet
Maquoketa	Shale	108–209 feet
Galena	Dolomite	240 feet
Platteville	Limestone	50 feet

All of these formations occur at the surface over wide areas, with the exception of the Platteville, which is found only in the valley of Galena River in the northern part of the district. The strata have a general dip to the southwest of about 17 feet to the mile, and on this monoclinal structure are a series of slight, hardly noticeable anticlines and synclines.

The most conspicuous topographic feature in the county, aside from the bluffs of the Mississippi Valley, is a more or less

[1] Published by permission of the Director of the Illinois Geological Survey.

FIG. 1.—A diagram showing the relations of the Niagara and Galena plains to each other and to the rock structure of the district. The upper dotted line represents the Niagara plain, and the lower dotted line the Galena plain. The uppermost rock formation is Niagara dolomite and the lowermost is Galena dolomite. Between the two is the Maquoketa shale, represented by dashes.

extensive and definite plain midway between the skyline and the valley bottoms. Its surface is broken by mounds and ridges above it, and by many sharp valleys below it. For convenience this may be called the *intermediate plain*. The mounds and ridges which stand on the intermediate plain and whose tops form the upland come up to a somewhat common level, in such a way that if the low land were filled up to their tops the region would be a nearly flat plain. The upper dissected plain lies everywhere on the Niagara dolomite, and the intermediate plain follows more or less closely the surface of the Galena dolomite; hence the upper plain is here called the *Niagara plain* and the intermediate surface the *Galena plain*. These two plains, the first now almost entirely dissected and the latter somewhat but less so, constitute the problems of this paper. Their general relationships are shown in Fig. 1.

The Niagara plain was known to Hershey[1] as "Peneplain No. 1," and he considered it to be a true peneplain partly dissected, of Cretaceous age. Bain[2] mentions the plain and seems to agree with Hershey concerning it. The upper plain was also known to Grant and Burchard[3] who state that "the facts observed

[1] *Am. Geologist*, XVIII, 75–78.

[2] *Bull. U.S. Geol. Surv. No. 294*, p. 15.

[3] *Lancaster-Mineral Point Folio*, U.S. Geol. Surv., p. 2.

within these two quadrangles are not sufficient to determine whether the upper plain—that is, the one lying above the Niagara escarpment—is a peneplain or a structural plain, and its general history outside of these two quadrangles has not yet been completely worked out, though its age is probably Cretaceous." A plain probably to be correlated with the Niagaran plain was recognized and called the "Allamakee Peneplain" by Calvin[1] in his report on Allamakee County, Iowa. The intermediate plain has been referred to by Hershey as "Peneplain No. 2," and by Bain, and by Grant and Burchard as the "Lancaster Peneplain," and it has been assigned by them to the Tertiary period. Calvin and Leonard make no note of such a plain in the reports on Allamakee and Clayton counties in Iowa. The Cretaceous and Tertiary ages of these respective plains seem to have been tentatively established by their relation to Cretaceous deposits in Minnesota and Iowa, and to Tertiary deposits in the Gulf region. There is little or no evidence of the dates of formation of the plains in Jo Daviess County, and their ages do not form the problems of this paper.

It seems advisable here to describe and interpret these plains, as seen in Jo Daviess County, with a view to determining if there are any other possible explanations beside that of peneplains. The purpose of the discussion is twofold. First, it is hoped that it may lead to a true interpretation of these plains and an understanding of the physiographic history of the region in which they are found. Secondly, an attempt is made to bring out the criteria for distinguishing upland plains of certain origins and histories from those of other origins and histories. It is believed that criteria for distinguishing raised and partly eroded peneplains in regions of folded strata, such as the Appalachian Mountains, are fairly well worked out; but that many of these criteria will not apply in regions of horizontal or nearly horizontal structures, and that the characters of peneplains in such regions are not so well known as they should be and have not been given as critical study as they deserve.

THE NIAGARA PLAIN

In most places where the Niagara dolomite is found in Jo Daviess County, its top has an even skyline when seen from a distance and a flat surface as seen when it is traversed. It is always a hard

[1] *Geology of Allamakee County*, p. 43.

pull for a horse when one is driving up the upper slopes, but, once the top is reached, the road has little grade. This can be well seen on the upland over the Great Western tunnel, or on the hills around Elizabeth, or almost anywhere on the upland surface. Even in the north part of the district the Niagara-capped mounds are flat topped, and those which stand in east-west lines come up to almost a common level. It is clear that if all the valleys were filled up to the tops of the mounds, the resulting surface would be nearly flat, and the presumption is strong that there was once a plain here which has since been dissected. The mounds in the north part of the district reach elevations of 1,170, 1,152, 1,160, etc. In the central part, the mounds and the tops of the Niagara-capped ridges reach 1,112, 1,145, 1,065, 1,060, 1,072, etc. In the south portion of the district, considerable areas of the plain are found at 944, 964, 1,027, 1,004, and 1,000 feet. That is, if this plain were reconstructed, it would slope south and southwest about 175 feet in 16 miles, or about 11 feet to the mile. In Wisconsin, a few miles north of this district, this same surface on the Niagara dolomite reaches elevations of 1,400 feet, showing a continued rise in that direction. It is seen then that this plain, if reconstructed, would slope in the direction in which the rock strata dip and at about the same angle.

The origin of this plain is now in question. There are at least four possibilities: (1) it is an old peneplain uplifted and dissected after its formation by streams; (2) it is a plain made by a hard layer of rock at this stratigraphic horizon; (3) it is the original sea bottom which, after emerging, remained low and flat for a long time after the Niagaran epoch; or (4) it is the result of the erosive action of ocean waves cutting back on the land, at a time subsequent to the deposition of the Niagara dolomite and any other formations which may have been laid down on it, the present remnants resulting from the partial erosion of the surface by streams following uplift relative to the sea. The correct one or ones of these four hypotheses ought to be determinable by close field observation.

1. If such a flat is a dissected peneplain, (*a*) it is likely to have hills standing above it, which were left unreduced in the former cycle of erosion; (*b*) the surface is likely to have some relief; (*c*) the

thickness of the formation on which it is developed is likely to vary to a degree corresponding with the relief of the surface; (*d*) it is not likely to be parallel to underlying strata, but to rise or fall stratigraphically; (*e*) it would be expected to slope in the general direction, corresponding to the direction of flow of the streams that made it, unless tilting took place after its formation; (*f*) much of the plain might be covered with river detritus such as fine gravel, sand, and silt, similar to the materials of river-made plains today. If such a plain is not parallel to underlying strata, but lies across their beveled edges, particularly if the strata are known to have constant thicknesses where undisturbed, it is almost certainly a result of erosion going to a late stage—a peneplain. This might not hold if the strata were the result of near-shore deposition, and thinned out shoreward.

If the characteristics of the Niagara plain be compared with this set of features expected on a raised and partly dissected peneplain, they are found to correspond only in part. Concerning the plain as it is in these quadrangles, (*a*) no distinct hills stand above it; (*b*) the flat has little relief—probably no more than could have been given it by erosion following the uplift; (*c*) the thickness of the formation under it varies slightly but not greatly in short distances; (*d*) its surface does not rise or fall appreciably in the stratigraphic section, even when considerable distances are considered; (*e*) it does slope in a general direction and at about the angle expected for a peneplain; (*f*) no sand or gravel or stream alluvium were discovered on the flat, and it is certain that no great amount of such material was there and has been subsequently removed, for it is not found on the bordering slopes, and some of the plain has been unaltered by any agent which could remove the alluvium. From the foregoing, it is seen that this plain is not clearly a raised peneplain; neither is it surely not a peneplain. If traced beyond the limits of this region, and found there to go from Niagara to Maquoketa to the north and from Niagara to something younger to the south, it will have been proven, nevertheless, to be a peneplain.

2. In a second cycle of erosion, a flat of considerable magnitude might be formed on the top of a hard layer of rock, by the removal

of softer material from above, provided the streams were not able to cut through the hard formation for a long period of time. Such a plain would be essentially a peneplain, with the difference that its position is determined by a hard stratum, instead of by base level, and that it would require no uplift to start its dissection; dissection would result when the main stream had cut through the hard formation. It would have essentially the same characteristics as a true peneplain, with the marked exception that it would be parallel to the layers of rock, and remain at the same stratigraphic position over wide areas.

If the Niagara plain be tested by these criteria, again no definite conclusion can be drawn. As the flat is everywhere located on the Niagara, lies everywhere near the top of the massive member of that formation, and about 150 feet above its base, and as it has all the other characteristics of a true peneplain, it may be said to fit the second hypothesis better than the first.

3. Or is the Niagara plain the original surface which emerged from the sea at the end of the Niagaran epoch, and has suffered dissection since then? A surface having had such a history should have somewhat different characteristics from one developed in either of the ways previously outlined. (*a*) There would be no marked hills standing above the remnants of the plain, for there were no other strata above it from which hills could have been formed. (*b*) The thickness of the underlying formation would be expected to be uniform, except for possible differences in the amount of deposition on the bottom of the sea, or erosion since emergence from the sea. (*c*) The plain would have little or no relief, unless roughened after its emergence, by streams, wind, etc. (*d*) Like the plain developed on a hard layer, the surface would follow the rock structure, not rising or falling appreciably with reference to the strata. (*e*) Any slope the plain has would be the slope, in direction and amount, of the old sea bottom, unless tilting occurred during emergence or later. (*f*) No river detritus should be found on this surface, but instead material deposited at the shoreline as the shore receded over it, if anything. (*g*) In this case also, if the bottom of the old sea has been preserved as the plain, it might be expected that somewhere the old shorelines might be found as raised cliffs,

old beaches, etc., in places where protected from later erosion. (*h*) Marine fossils might be found on the surface of the plain.

Of these features the plain under discussion has some and lacks others. (*a*) It has no hills above it; (*b*) the underlying formation has a sufficiently uniform thickness to give the idea of an original plain; (*c*) the relief of the surface is sufficient but not too great; (*d*) the plain follows the structure fairly closely; the slope of the flat may be either that of the old sea bottom, or the result of slight subsequent tilting; (*f*) and (*h*) the materials of the surface afford no evidence, because there is a complete lack either of river detritus or of the shells of terrestrial or marine animals; (*g*) even if old shorelines were preserved at the edge of the ancient sea bottom, they would be found only at the margin of the plain, and this is outside the region under discussion. But no such shore features have been reported, and in all probability none exists. Even if the plain had had such a history as is here outlined, the factors mentioned in (*f*), (*g*), and (*h*) would not be expected to have persisted through such a lapse of time as the hypothesis presupposes.

4. There remains one other hypothesis to be analyzed and tested. If this plain is the result of marine erosion, it would have most of the characters of a peneplain due to stream erosion; that is, (*a*) it might have erosion remnants on its surface; (*b*) it might lie parallel with the strata in a general way, but it would be surprising if the two were exactly parallel; (*c*) it would slope in one general direction, in this case the slope being the oceanward slope of the old sea bottom; (*d*) some of the plain should be covered with marine sediments—debris deposited on the surface after its erosion, but before the recession of the sea. This plain would differ from a true peneplain in having little or no relief before dissection, and in having correspondingly little variation in thickness of the underlying formation within short distances. In addition, a plain so made must have been bounded originally by a shoreline of some sort, and this might or might not have been preserved, if the flat was preserved. Also, as the sea cut its way over the rock surface, and the flat off shore became wider and wider, the places eroded would gradually become sites of deposition, and this débris might

be found on the plain, either cemented into hard rock or uncemented.

Again the Niagara plain has some of these characters, but not all. So far as slope and the apparent original relief and the uniformity of thickness of the underlying formation are concerned, the plain might be explained along the lines of this hypothesis, but the correspondence of the surface with the structure of the beds, the absence of near-shore marine deposits, the absence of all shorelines, and the fact that no other large plains are known which seem to have been made in this way, would seem to point to some one of the other hypotheses as the true explanation of the flat.

Conclusion.—After this discussion it is apparent that the origin of the Niagara plain is from this region not perfectly clear, but that some speculation at least is warranted. The facts that the plain is so distinctly related to structure and that it shows no conclusive evidence of having been peneplained point toward the conclusion that it is the original plain or a structural plain (or both), rather than an old peneplain or a plain of marine erosion. It is unlikely that a peneplain would happen to be formed so closely parallel to structure as this flat is *over wide areas*. Still it is possible that, when traced into other regions, this parallelism will fail, and the flat will be proven to be a peneplain. It has been so long since the Niagaran epoch, that it appears extremely unlikely that a flat emerging from the sea at that time could have remained undestroyed until now, unless perhaps it be conceived that the surface took a position very near to sea-level from the start, and held that position until uplifted in relatively recent times. Perhaps it is a combination of a true peneplain and a structural plain, the flat having been developed on the hard Niagara dolomite at a level which was near grade for the streams of the region at that time. Possibly the flat is an original marine plain and also a structural plain, the last deposit in the sea having been made into hard rock (the massive Niagara). Most likely the plain under discussion is an ordinary structural plain, the surface having been developed due entirely to the hard Niagaran dolomite which held up the streams at that level until all overlying strata were removed, before the dolomite formation was finally cut through and dissection of the plain began.

THE GALENA PLAIN

The Galena plain is best developed and distributed over widest areas and can be seen to best advantage in the district around the towns of Scales Mound, Apple River, Warren, and Stockton. Here is a surface 150 feet lower than the tops of the mounds and ridges of the Niagara plain, and 150–200 feet above the stream beds. Except for the elevations above it and the depressions below it, the plain forms a wide area of slight relief. In Section 8, Rush Township, where its surface has not been modified, it has a relief of less than 20 feet for a whole mile. This is a little more flat than the average, but not greatly so. This plain is practically confined to the northern two-thirds of the county; it does not appear to any appreciable extent in the southern one-third, and is lacking entirely along the south edge of the Galena and Elizabeth quadrangles. In the vicinity of Galena it appears in flattish or rounded divides midway between the upland mounds and the valley bottoms. By close observation, similar features may be seen about as far south as the Great Western tunnel in the Galena quadrangle, and to about the latitude of Stockton in the Elizabeth quadrangle. If reconstructed, this plain also would slope southward at a low angle.

Stratigraphically, the Galena plain is located on the hard Galena dolomite or only slightly above it in the Maquoketa shale. The broad flat in the district around Scales Mound, Apple River, Warren, and Stockton is underlain directly by the upper thin beds of Galena, or locally far from the main streams by 5–15 feet of Maquoketa shale above the Galena. The rounded divides and narrow flats around Galena and north and south of that place are underlain by Maquoketa shale of thicknesses up to 30 feet. In the south part of the county where the Galena dolomite dips beneath the surface, the flat cannot be seen.

In the case of the Galena plain, only three of the four above-discussed means of origin are possible. It cannot be an original marine plain of deposition, because the mounds and ridges of Niagara dolomite stand above it, and have been made by processes of degradation since the recession of the sea. It may, however, be a structural plain on the hard Galena dolomite, or it may represent the beginnings of a true peneplain, or perhaps it is conceivable that it was carved out from the shale and dolomite above the Galena

by the waves of a slowly advancing sea. In either of the first two cases, streams were the agents of its formation, the cause of the flat only being different. If a structural plain, the flat was developed by streams, because they flowed down the dip of the top of the hard dolomite, scouring off the softer shale. If the flat is a remnant of a true peneplain in its beginnings, it was developed by streams because they had reached grade, and the region had been developed to an early peneplain stage before uplift allowed dissection in another cycle of erosion.

After analysis of the various features of this plain, the idea of marine erosion seems to be untenable. On such an extensive plain, marine near-shore deposits would have been sure to be deposited, and no suggestions of such deposits are found on the surface. Under this hypothesis, also, the mounds and ridges standing on the plain must have been islands, headlands, peninsulas, etc., and their sides must have suffered erosion by the waves which made the plain; that is, their sides must be shorelines of erosion. As most of these elevations stand out boldly on the plain, far from the main streams and valleys of the present cycle of erosion, it must be considered that they are about as they were left by the agent or agents which made them. This being the case, evidence of the work of waves on their sides should be visible now. But in contrast to this, the slopes of these mounds and ridges show every evidence of stream work, and have very clearly not been eroded to their present shape by waves; especially is this true in the central and southern parts of the county where the uplands form the stream divides and have the dendritic arrangement characteristic of topographies developed by the work of streams.

The Galena plain has all the main earmarks of an incipient peneplain after uplift and partial dissection, except that it follows the Galena dolomite with surprising closeness: (1) it consists of extensive flat areas lying between uplands and lowlands, and in such positions flat areas are not developed except for some special reason; (2) aside from recent dissection, it has about the flatness to be expected on a peneplain; (3) distinct erosional hills stand above it; (4) it slopes gently in the direction in which the present streams flow; but (5) it follows the top of the Galena formation

rather closely, and seems to disappear where that formation dips beneath the surface. However, close study of stratigraphy in connection with this flat shows the coincidence of flat and structure to be not so striking after all. In southwestern Wisconsin, Grant and Burchard[1] find evidence of a dissected peneplain on the upper part of the Galena formation, which now has an altitude of 1,000–1,100 feet. In the northern part of Jo Daviess County this surface is above a few feet of Maquoketa, and the shale formation gets slightly thicker under the flat to the south. That is, to a small degree the flat does lie across the beveled edges of different formations. These relationships are shown in Fig. 1. The Galena plain is believed by the writer to have been a true but only partly developed peneplain, but one somewhat controlled by rock structure.

The feature which seems at first to militate against the peneplain interpretation is the disappearance of the flat where the Galena dolomite dips below the surface. However, this may be explained. If the peneplain was developed on the Galena and Maquoketa formations as shown in the diagram (Fig. 1), the Maquoketa shale was thickest under the southern part of the plain. When the plain was uplifted and the streams were rejuvenated, the shale was attacked most vigorously downstream. The shale being soft, its dissection resulted in speedy destruction of the plain where the shale was thick; where lacking, the plain was preserved longer. Even where there was a little shale under the plain the main streams cut through it rapidly, and then were held to slow cutting by the hard Galena dolomite. Working in the hard rock, they did not send out tributaries as readily as they did in the soft shale farther south, and the flat was protected. It is believed then that the plain is a partly developed peneplain, the southern part of which, after uplift, has been destroyed because the shale which underlay this part was exposed and not resistant to erosion. The plain is more distinct in the central part of the district, and in the northern part it is very well preserved, because of the hard dolomite near or directly under it. Possibly also the dolomite had some influence in the development of the plain as well as in its modification.

[1] *Lancaster-Mineral Point Folio*, U.S. Geol. Surv., p. 2.

CONCLUSIONS

The mounds and ridges in Jo Daviess County, Illinois, are remnants of a plain which is either an old peneplain or a structural plain, and in the mind of the writer the latter interpretation is more likely to be correct than the former. It is probable that the district remained under the sea for some time following the deposition of the Niagaran rocks now found here, and that emergence took place some time after the Niagaran epoch. The region was then subjected to erosion, and a broad plain was developed on the hard Niagara dolomite. Finally this formation was cut through by the major streams, and the Maquoketa shale underlying was rapidly removed. The streams reached grade at the level now represented by the Galena plain, which in this district happened to lie in the upper part of the Galena formation and the lower part of the Maquoketa shale. Before the mounds and ridges on this plain had been brought low, probably in Tertiary time, an uplift occurred and the streams were again allowed to deepen their valleys in the old plain.

It is realized that a close study of these plains over wide areas will be necessary before a complete understanding of them is obtained. The whole driftless area seems to be the field of work. The writer hopes to do something more toward the solution of the problem at a later date.

THE SKULLS OF ARAEOSCELIS AND CASEA, PERMIAN REPTILES

S. W. WILLISTON
University of Chicago

There are few Permian reptiles of greater interest at the present time than the peculiar one I briefly described in this journal[1] three years ago as *Araeoscelis gracilis*. At the time of the description the material in the University collections had not been prepared, and it was in the hope of acquiring additional material from the Craddock bone-bed near Seymour, Texas, whence the type specimens came, that I have delayed the publication of further details concerning the genus. Unfortunately the bone-bed seems to be exhausted, at least so far as *Araeoscelis* is concerned. The material of the University has now been worked up thoroughly by Mr. Miller, and is sufficient to reveal nearly all the details of the skeletal structure of this strange reptile, which in many ways departs widely from all other known reptiles of the Texas deposits. The object of the present paper is to describe briefly the structure of the skull for the information of others working on allied material. The full description of the skeleton, with illustrations, will be published later.

The skull, as shown in the accompanying figures, will not require a detailed description at this time. Suffice it to say that the structure of the temporal region is determined positively, save perhaps the precise union of the squamosal and jugal. The absence or vestigial condition of the lacrimal I am also confident about. The skull in life may have been slightly narrower than is shown in the figure; I do not think it could have been wider.

It has been suggested, especially by Huene, that *Araeoscelis* shows affinities with the lizards. The structure of the skull confirms this suggestion in a startling way. Really about all that seems necessary to convert *Araeoscelis* from a "theromorph" into a primitive squamate reptile is the reduction of the squamosal from

[1] *Journal of Geology*, XVIII, 587, October, 1910.

below and a greater mobility, or streptostyly, of the quadrate. Our specimens show a loose union of the squamosal with the quadrate, and it was the absence of the squamosal and postorbital in one specimen which induced me at first to believe that the whole temporal region was open. It is very possible that a like condition existed in *Varanosaurus* and that it may eventually be found to have a superior temporal vacuity only. I hope to decide this point by a study of additional material later.

I cannot be sure of the differentiation of the elements of the slender parietal arch, but I think it is very probable that it is formed

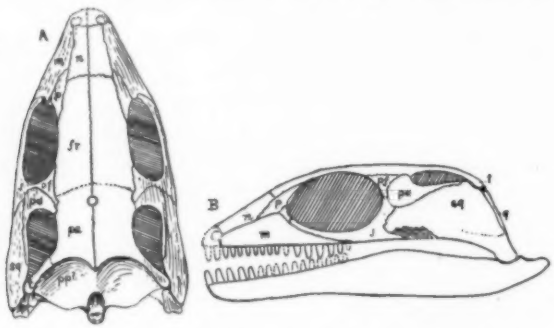

FIG. 1.—*Araeoscelis gracilis* Williston. *A*, skull, from above; *B*, the same from the side, both ½ natural size; *fr*, frontal; *j*, jugal; *m*, maxilla; *n*, nasal; *p*, prefrontal; *pa*, parietal; *pf*, postfrontal; *po*, postorbital; *pp*, supraoccipital and paroccipital; *q*, quadrate; *sq*, squamosal; *t*, tabulare.

more or less by the tabulare, as in the Lacertilia. The exclusion of the postorbital from the orbit seemed almost incredible, but I am convinced that such was the case in *Araeoscelis* by the agreement of several specimens. This exclusion would seem to mean that the single bone found here in the Lacertilia and Mosasauria is really the fused two bones, the postfronto-orbital.

Whether or not *Araeoscelis* was phylogenetically related to the Squamata scarcely a doubt can remain that the single arch in lizards was the result of the progressive loss from below of the squamosal, and not the loss of the lower arcade in some rhynchocephalian reptile, as has been generally believed. The Squamata undoubtedly arose from just such a type of skull as is shown in *Araeoscelis*.

Broom[1] has recently expressed his belief that *Araeoscelis* is closely allied to *Bolosaurus*, a genus hitherto placed among the Cotylosauria by Cope, Case, and Huene, the type of a distinct family, the Bolosauridae. He has described a new genus from among the material in the American Museum which had hitherto been confounded with *Bolosaurus*, but of whose distinction from *Araeoscelis* he was not sure. So far as his descriptions and figures go (aside from the restorations), there is nothing to distinguish

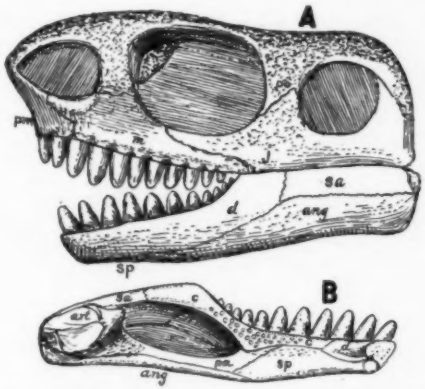

FIG. 2.—*Casea Broilii* Williston. *A*, skull from side; *B*, left mandible, both ½ natural size; *art*, articular; *ang*, angular; *c*, coronoid; *d*, dentary; *m*, maxilla; *po*, postorbital; *pm*, premaxilla; *sp*, splenial.

Ophiodeirus from *Araeoscelis*, save perhaps in the teeth, in which I think he is in error. The teeth of *Araeoscelis* are simple throughout, without accessory cusps, and they are distinctly thecodont. There are, however, some differences in the teeth among the material which I have referred to *Araeoscelis*. Typically there are fourteen, or possibly fifteen, teeth in the maxilla, of the size I have shown in the figure. Another specimen, consisting of the maxilla and mandible only, has at least sixteen teeth in the maxilla, all of a uniform small size; yet another skull has fourteen teeth, all of nearly uniform size. *Bolosaurus* comes from the Wichita beds, doubtless

[1] *Bull. Amer. Mus. Nat. Hist.*, XXXII, 509, October, 1913.

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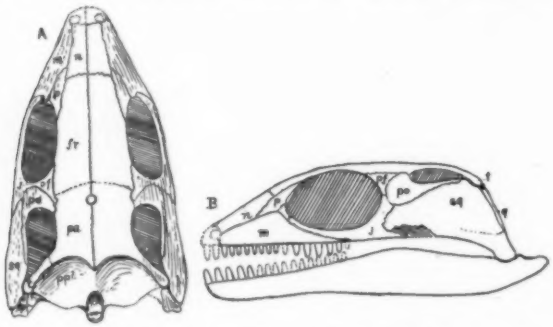

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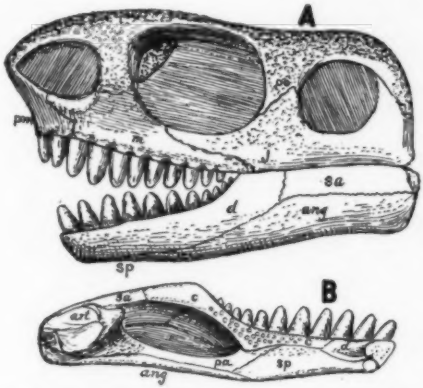

FIG. 2.—*Casea Broilii* Williston. *A*, skull from side; *B*, left mandible, both $\frac{3}{4}$ natural size; *art*, articular; *ang*, angular; *c*, coronoid; *d*, dentary; *m*, maxilla; *po*, postorbital; *pm*, premaxilla; *sp*, splenial.

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of Carboniferous age; *Araeoscelis* from the Clear Fork, of Lower Permian age. Aside from the remarkable cuspidate and acrodont teeth, which are of more than generic importance, the structure of the skull in *Bolosaurus striatus*, as figured by Broom, separates the two genera into distinct orders.

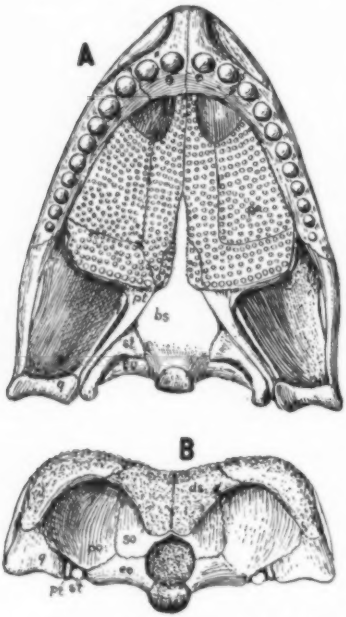

FIG. 3.—*Casea broilii*. *A*, skull from below; *B*, the same from behind; both ¾ natural size: *bs*, basi sphenoid; *eo*, exoccipital; *ds*, dermosupraoccipital?; *po*, paroccipital; *pt*, pterygoid; *pa*, palatine; *q*, quadrate; *st*, stapes.

A matter of more importance than the synonymy of *Ophiodeirus*, is the relationship of *Kadaliosaurus* Credner, from the Lower Permian of Germany. My attention to such possible relations was first called by a letter from Professor Jakolov written on the receipt of my paper containing the original description of *Araeoscelis*. He mentioned the fact that he had certain bones from Europe which seemed to be identical with those figured by me. A study of Credner's figures and description of *Kadaliosaurus* confirmed my belief of the affinity between the two genera, as I have already published. In showing our specimens to Dr. von Huene on his late visit to Chicago, I called his attention to these resemblances, in which he immediately concurred. Last April I had the privilege of studying the type specimens of *Kadaliosaurus* and *Paleohatteria* in Leipzig, for which my thanks are due to Professor Stille and Dr. Henkel. The material of *Kadaliosaurus* is imperfect, but, so far as it goes, I could not distinguish the genus from *Araeoscelis*, save by the greater size of the specimen and the presence of ventral ribs, both dubious characters.

It would of course be premature to say that *Kadaliosaurus* and *Araeoscelis* are congeneric, but I cannot resist the belief that they are closely allied at the least. Possibly here, as so often elsewhere, the conclusions based on negative evidence are unreliable. It is not at all improbable; indeed I think it very probable, that the isolation of the American Permian fauna, in which I have concurred, will eventually be shown to be much less than has been supposed.

As a postscript I may mention, that, notwithstanding the general accuracy of Credner's descriptions, his interpretation of the scapula and coracoid of *Paleohatteria* is quite wrong. The genus has a normal pectoral girdle, with the coracoid closely united to the scapula, and probably with the usual supracoracoid foramen. The scapula is rather short, perhaps an indication of subaquatic habits. As I have stated elsewhere, I could find no indication of a supratemporal vacuity in *Paleohatteria*, and much evidence that there was none. I may also add, that from an examination of the specimens of *Haptodus* in the Paris museum, kindly granted me by M. Thevenin, I am confident that the two genera are distinct. *Paleohatteria* has a distinctly rugose skull, while that of *Haptodus* is quite smooth.

VARIATIONS OF GLACIERS. XVIII[1]

HARRY FIELDING REID
Johns Hopkins University, Baltimore, Maryland

The following is a summary of the *Seventeenth Annual Report* of the International Committee on Glaciers.[2]

THE REPORT OF GLACIERS FOR 1911

Swiss Alps.—The general retreat of the glaciers in recent years was interrupted in the last two years by the advance of more than eight glaciers; but all of these glaciers have begun to retreat again. The remarkable heat of the summer of 1911 caused very great melting at the ends of the glaciers and seems to have brought their advance to an end.

Eastern Alps.—Here we have conditions very similar to those of the Swiss Alps. The hot summer of 1911 caused a very marked elevation of the snow line and the slight advance noted in 1910 was checked, and practically all the thirty-five glaciers under observation were in retreat. One only seemed to be stationary. The glaciers this year give no indication that the general retreat, which has been in progress for some time, has come to an end. The snow line is higher and the lower ends of the glaciers are flattened out by melting.

Italian Alps.—Observations at various points on the Italian side of the Alps show that, with one or two exceptions, the glaciers are continuing to retreat. On the south side of Mont Blanc the changes are very slight and the glacier in the Allée Blanche has actually advanced about eight meters.

French Alps.—In spite of the very hot summer of 1911 the glaciers on the French side of the Mont Blanc chain show a tendency to advance, and there is a distinct thickening of the glaciers a short distance above their ends. The glaciers of the Maurienne

[1] Earlier reports appeared in the *Journal of Geology*, III–XXI.

[2] *Zeitschrift für Gletscherkunde*, VII, 37–47, 191–202.

continue to retreat but very slowly. The great heat of the summer of 1911 does not appear to have greatly affected the glaciers in the northwestern part of the Pelvoux massif and in the Grandes Rousses. The general retreat has apparently been stopped in these mountains. The accumulation of snow has been increasing and this has protected glaciers from excessive melting.

Swedish Alps.—The Swedish glaciers lie pretty far north. Of the five under observation, four are advancing and one is stationary.

Norwegian Alps.—The interior glaciers of the Jotunheim are retreating; only two out of twenty-seven observed show slight advance. In the Folgefon and the Jostegalsbrae, near the west coast, thirteen glaciers are advancing and sixteen retreating. In the more northerly regions we find nine glaciers advancing and two retreating. It is rather interesting to note that different parts of the same glaciers are retreating at different rates.

Russia.—A number of glaciers in the Caucasus and several in the Altai Mountains are distinctly in a phase of retreat.

REPORT ON THE GLACIERS OF THE UNITED STATES FOR 1912[1]

In Colorado, the Hallet Glacier shows a trifling expansion (Mills). Although the snowfall during the winter and spring was very heavy, no change was apparent in the length of the Arapahoe Glacier (Henderson).

Mr. F. E. Matthes, who has been engaged in mapping Mount Rainier, sends me the following information regarding its glaciers:

> According to the testimony of Joseph Stampfler, a guide in the Mount Rainier National Park, who has lived since early boyhood at Longmire, in the valley of the Nisqually River, the Nisqually Glacier in 1885 extended to the point now occupied by the bridge on the government road to Paradise Park. The glacier accordingly has made a retreat of one thousand feet since 1885. In that distance it has left no marked morainal ridges, and the inference is that its retreat has been a fairly steady one.
>
> The retreat of the glaciers has been marked during the last four years (1909–12). The Paradise Glacier, which prior to 1909 descended from an irregular rock bench about 250 feet high to gather again on the flat terrace below (elevation 6,100 feet), now barely reaches the terrace in a few places.

[1] A synopsis of this report will appear in the *Eighteenth Annual Report* of the International Committee. The report on the glaciers of the United States for the year 1911 was given in *Jour. Geol.*, XXI, 423–26.

The ice cave in its front, formerly much visited by tourists, has disappeared. Joseph Stampfler states that the Paradise Glacier once covered the entire terrace to its very edge. He cannot fix the exact date when the glacier began to withdraw from the edge, but he knows that it must have been in the early eighties. This edge is now more than two thousand feet in front of the ice.

The névé line on the Cowlitz, Nisqually, Van Trump, Wilson, and Tahoma glaciers, situated on the southeast, south, and southwest flanks of the mountain, appears to lie normally at an altitude between 7,000 and 7,500 feet. During the abnormally dry summer of 1911 the névé line rose to 8,500 feet or higher. In certain places on the Paradise, Nisqually, and Van Trump glaciers old ice was exposed as high as 9,500 feet. On the Tahoma Glacier (southwest side) the ablation was less conspicuous.

Mr. Matthes has emphasized the fact that the summit of Mt. Rainier is not the principal reservoir of its glaciers, but that the cirques and even the flanks of the mountain collect more snow than the summit. This is due not only to their larger area but also to the fact that the snowfall reaches its maximum amount at a much lower altitude than the summit of the mountain.[1]

Professor Lawrence Martin sends me the following information regarding Alaskan glaciers:

Kenai Peninsula.—Spencer Glacier is said by A. W. Swanitz to be receding more rapidly than in 1911, on account of the artificial diversion of a glacial stream to the ice border.

Copper River.—The Allen Glacier, on the lower Copper River, upon whose stagnant, moraine-covered terminus the Copper River and Northwestern Railway runs for 5½ miles, is reported by Caleb Corser to have commenced to advance during the summer of 1912. It was thicker and more crevassed than in 1911; and in places formerly covered by moraine, blue ice appeared. The northern margin is said to have advanced a half-mile. The largest glacial stream on the northern side of Allen Glacier has left its former channel for a new course a mile farther west. It has increased greatly in volume, and shifts frequently, causing much trouble to the railway on the northern alluvial fan of outwash gravels.

Heney and Grinnell glaciers were still advancing slowly in 1912. Childs Glacier (presumably the northern margin) advanced 60 feet between July 15 and September 30.

Miles Glacier seemed to be advancing farther into the frontal lake than in 1911. On August 16, 1912, a sudden flood (perhaps from the draining of a glacier-margin lake) swept down the Copper River from Miles Glacier, raising

[1] "The Undescribed Glacier of Mount Rainier," *The Mountaineer*, Seattle, V, 42–57; "The Glaciers of Mt. Rainier," *Appalachia*, XIII (1913), 24–27.

the water level 12 feet at Childs Glacier bridge, and doing much damage twenty miles farther south.[1]

Wrangell Mountains.—Kennicott Glacier was unchanged from 1911 to 1912; the descriptions of the upper portion of this glacier and its tributaries in 1911 and 1912 by Miss Dora Keen, who ascended Mount Blackburn in the latter year, indicate no significant present-day activity. Chitina Glacier is said by Benno Alexander to have advanced between 1911 and 1912.

St. Elias Range.—The previously unexplored glacier system of the St. Elias Range between Mts. Logan and Natazhat was partly mapped in 1912 by the American Boundary Survey party under D. W. Eaton. The Chitina Glacier, whose chief tributaries are Logan Glacier from the southeast and Anderson Glacier from the northwest, is 3½ to 5 miles wide at the terminus. Logan Glacier is 45 or 50 miles long and 2½ miles wide. It probably originates near Mt. Logan on a through glacier divide connecting with the Seward Glacier of the Malaspina system. The lower portions of Logan and Chitina glaciers are covered with ablation moraine and forest, including trees at least one hundred and ninety-three years old. The heavy growth of coniferous forest along the margins of Logan Glacier shows that it has not been larger than now for several centuries. The photographs and descriptions by Mr. Eaton show that Logan Glacier commenced a spasmodic advance in 1912 which widened and crevassed the upper portions of the glacier; ablation moraine material fell into crevasses; the glacier advanced over alders, and marginal lakes were formed. This activity after nearly two centuries of stagnation is probably the result of avalanches due to the earthquakes of September, 1899, in Yakutat Bay, which is less than 80 miles distant (only 50 miles from the divide between Logan and Seward glaciers). A small tributary of Anderson Glacier was also advancing actively in 1912.

Mr. C. G. Quillian, commanding the Unites States Coast and Geodetic Survey steamer "Mc Arthur," went close to the western edge of the Malaspina Glacier in May, 1911. He reports a new bay in the ice at the western edge of the glacier; its position indicates that the Guyot lobe of Malaspina Glacier has receded many miles. The new Coast Survey map (Chart 3002, March, 1912) indicates that this recession is about 9 miles, but Mr. Quillian's estimate is only 2½ to 3½ miles. The discharging face of the glacier within the bay was 200 to 250 feet high.

The writer of this review has concluded, from the study of a map and drawing made by Vancouver in 1794 and from a story handed down by the Yakutat natives, that the sea in the old Icy Bay of Vancouver reached to the Chaix Hills at the base of Mt. St. Elias in 1794. This involves the probability that the seacoast was subsequently pushed southward by the advance of Guyot

[1] For a detailed map of the lower Copper River glaciers see Lawrence Martin, "Gletscheruntersuchungen längs der Küste von Alaska," *Peterm. Mitt.*, LVIII, (1912, II), 78–81, 147–49.

Glacier, as was suggested in 1904 by Davidson. This advance of about 20 miles probably took place between 1847 and 1886. The ice front of the Guyot lobe practically maintained its advanced position at least from 1886 to 1909, and has since receded between 3 and 9 miles, forming a new Icy Bay, a little west of the old one. This results in the destruction of the Icy Cape salient of Guyot Glacier, one of the only two places where a tidal glacier entered the open waters of the Pacific Ocean.

The Canadian Boundary Survey party under N. J. Ogilvie found that Nunatak Glacier had receded about $\frac{1}{4}$ mile between 1911 and 1912.

Glacier Bay.—The same party measured a recession of $1\frac{5}{16}$ miles at Grand Pacific Glacier in Reid Inlet of Glacier Bay. This ice tongue receded at the rate of only about 1,500 feet a year in the twenty years before 1899. Since then it has retreated at the rate of over 4,300 feet a year from 1899 to 1906, 1,320 feet from 1906 to 1907, and approximately 3,300 feet a year from 1907 to 1911. Between September 2, 1911, when seen from a distance by the National Geographic Society's expedition under Tarr and Martin, and June 1, 1912, when visited and mapped by Ogilvie, this ice tongue retreated between $\frac{1}{4}$ and $\frac{3}{4}$ mile (according to accurate measurements by the Boundary Survey party, 14,520 feet in all from 1907 to June, 1912). In the two months from June 1 to August 1, 1912, there was a further unprecedented retreat of between one and $1\frac{4}{5}$ miles (5,000 to 7,425 feet). A portion of the terminus of Grand Pacific Glacier is now in British Columbia, so that the waters of Glacier Bay are partly Canadian. The following table summarizes the retreat of Grand Pacific Glacier:

Year	Amount, Feet	Rate per Year, Feet	Based on Observation by
1879–92	21,120	1,620	Muir, Reid
1892–94	2,500	1,250	Boundary Survey
1894–99	6,600	1,320	Gilbert and Gannett
1899–1906	30,360	4,337	F. E. and C. W. Wright
1906–7	1,320	1,320	Morse, Klotz
1907–11	13,200	3,300	Tarr and Martin
1911–12 (June)	1,320	7,320*	W. J. Ogilvie
1912 (June 1 to Aug. 1)	6,000*		

This recession of 15 to 16 miles in thirty-three years is unique. The acceleration of retreat immediately after the 1899 earthquakes may be only a coincidence, for the still greater acceleration of retreat since 1911 can be explained only by a marked deficiency in the snow supply, which may have begun years ago.

Arctic Alaska.—In the mountains north of the Yukon River small glaciers were discovered in 1911 by P. S. Smith[1] and by A. C. Maddren.

[1] P. S. Smith, "Glaciation in Northwestern Alaska," *Bull. Geol. Soc. Amer.*, XXIII (1912), 566.

A general description of the glaciation of the Alaska Range has been given by Capps[1] so far as it is known. The greater development of glaciers on the southern slope of the range, as compared with the nothern slope, is ascribed to the greater snowfall and to the larger collecting grounds. The southern slope is about twice as long as the northern.

Tarr has reviewed the observations made on Alaskan glaciers and their variations. He emphasizes the influence of avalanches due to earthquakes in causing spasmodic advance of glaciers.[2] In association with Martin he has published details of the sudden advance of the Yakutat glaciers due to the earthquake of 1899[3] (see earlier reports of this series). Grant and Higgins have collected their observations on the glaciers of Prince William Sound and Kenai Peninsula (already mentioned in these reports) in a bulletin of the United States Geological Survey, with maps and illustrations.[4] Several other bulletins of the Geological Survey contain maps showing the location of glaciers, but the descriptions of the glaciers are very cursory.[5]

[1] Stephen R. Capps, "Glaciation of the Alaska Range," *Jour. Geol.*, XX (1912), 415–537.

[2] Presidential address before the Association of American Geographers, *Science*, XXXV (1912), 241–258; and *Annals of the Assoc. of Amer. Geographers*, II (1912), 1–24.

[3] R. S. Tarr and Lawrence Martin, "The Earthquakes of Yakutat Bay, Alaska, in September 1899." *U.S. Geol. Survey, Prof. Paper No. 69*, chap. iv.

[4] *Bull. No. 526.*

[5] F. H. Moffit and Stephen R. Capps, "Mineral Resources of the Nizina District, Alaska," *Bull. No. 488;* Stephen R. Capps, "The Bonnifield Region, Alaska," *Bull. No. 501;* "The Yentna District, Alaska," *Bull. No. 534;* F. H. Moffit, "Headwater Regions of Gulkana and Susitna Rivers, Alaska," *Bull. No. 498.*

Reviews

"The Skeleton of *Ornithodesmus latidens*." By R. W. Hooley. In the *Quarterly Journal of the Geological Society*, LXIX (1913), 272–422; pls. XXVI–XL.

The present paper is of much interest and of importance in any discussion as to the relationships and structure of the pterodactyls. By diligent collecting Mr. Hooley has brought together a very considerable portion of the skeleton of a remarkable form hitherto known only doubtfully from fragments. *Ornithodesmus* is a pterodactyl of considerable size, more primitive in some respects than the American forms, but with certain peculiarities all its own. Its narial and antorbital vacuities are of enormous size; it has teeth in the front part of the jaws; a large keel on the sternum; a notarium and vertebral articulation of the scapula; doubtless a short tail; and no pubic opening.[1]

The femur Mr. Hooley describes as different from that of *Pteranodon* or *Nyctosaurus* in the divergence of the neck, but really there is no essential difference, the articular surface in all being at the extreme top, and its significance has already been discussed by the writer. Mr. Hooley believes that the wing metacarpal was shorter than the forearm; but that remains to be proved.

The pterodactyls offer a fertile field for speculation, and the author has availed himself of the opportunity presented by *Ornithodesmus* to propose a number of hypotheses as to the structure and habits of these strange reptiles, some of which are ingenuous, but the most of which seem doubtful to the present writer. He proposes an entirely new hypothesis as to the structure of the sternum, but one which is quite impossible of demonstration, if it be true, until the terrestrial ancestors of the pterosaurs have been discovered in Triassic rocks. He believes that the so-called manubrium, and the keel, whether large, as in *Ornithodesmus*, or small, as in *Pteranodon*, are really composed of the inter-

[1] While at Munich recently Dr. Stromer and the writer convinced themselves thoroughly of the presence of a true obturator foramen below the acetabulum, occupying its usual position in the early reptiles. Probably thorough search will reveal its presence in some form in all pterodactyls, definitely proving the fusion of pubis and ischium.

clavicle, to which the articulation of the coracoids has migrated and which is indistinguishably fused with the sternum proper.

The sternum is a comparatively late development in reptiles. In the primitive reptiles there was none, not even a cartilaginous one. The coracoids in all primitive reptiles met or nearly met in the middle line, underlain in their whole extent by the posterior prolongation of the interclavicle. Back of the coracoids, occupying the interval between their divergent hind borders and reaching to the pelvis, the under side was sheathed by ventral ribs in the majority of forms, leaving no space for even the smallest cartilaginous sternum. This condition has been found so often and in such perfect preservation among American Permo-Carboniferous reptiles that there can be no doubt of the entire absence of the sternum in all forms. Just what was the origin of the sternum, and the cause of its appearance, are of course yet unproven, but it seems to the writer extremely probable that the sternum is nothing more nor less than modified sternal ossifications in the parenchymatous tissue, of the same nature as the more posterior ribs and originally a part of the same series.

Evidence now seems conclusive that the plesiosaurs and ichthyosaurs are of very primitive origin, doubtless descended from terrestrial reptiles which had not yet acquired a sternum, and in which the coracoids met in the median line.

That the coracoids of the pterodactyls should have formed an articulation on the interclavicle in the absence of clavicles and the presence of an ossified or cartilaginous sternum is an improbable theory without any evidence that the writer can see to sustain it.

Mr. Hooley reaches some interesting conclusions as to the mechanics of the arm and forearm in *Ornithodesmus*, but which are not borne out by the American specimens of pterodactyls. He asserts that the radius, so far from its lying parallel with the ulna or in a pronated position, had acquired an over-supinated position, with its distal extremity on the dorsal side of the ulna. He also asserts that there was great freedom of movement in the carpus, not only dorsoventrally, but in an antero-posterior direction. With the arm extended and the elbow backward and the thumb in front, the humerus must necessarily occupy an oblique position or the radius is slightly pronated. With the radius crossing back of the ulna to the dorsal side, the palm of the hand would be turned forward. It is true that the wing metacarpal and the phalanges in their function of supporting the patagium have acquired an anomalous position in that the articulations have become antero-posterior instead

of dorsoventral; and doubtless this position has been acquired by a rotation on the carpus. But, to oversupinate the hand would turn the articulations anterior; and it seems very improbable. It may be added that the peculiar spiral position of the "deltoid" crest is a characteristic of all primitive reptiles.

As to the extreme freedom of movement in the carpus asserted by Mr. Hooley, one needs but to consult Dr. Eaton's excellent photographs of *Pteranodon* to be convinced of its impossibility, in that genus at least. That there was a considerable antero-posterior movement between the forearm and the wrist is not improbable, but that there was much movement dorsoventrally seems impossible.

As regards the classification of the Pterosauria, he makes some startling changes. He believes that most of the characters hitherto used, such as the shortening of the tail, the lengthening of the wing metacarpal, the development of a notarium and vertebral connection of the scapula, are all homoplastic characters, and the previous classification consequently an artificial one. He unites *Rhamphorhynchus* with *Pteranodon* in the Rhamphorhynchoidea; *Pterodactylus* he locates almost alone in the Pterodactyloidea; while for *Ornithodesmus*, *Dimorphodon*, etc., he makes a new sub-order, the Scaphognathoidea. And the grounds for this classification he finds almost exclusively in the degree of ossification of the facial part of the skull! Certainly there is more difference between *Rhamphorhynchus* and *Pteranodon* than between the latter and *Pterodactylus*, necessitating the resuscitation of Marsh's Pteranodontia. And then the next proposition doubtless will be to erect *Dimorphodon* into a sub-order all its own, till finally we shall have every genus a family and every family a sub-order! The writer disagrees with the proposed classification *in toto*.

S. W. WILLISTON

Untersuchungen über die Bildungsverhältnisse der ozeanishen Salzablagerungen, in besondere des Stassfurter Salzlagers. By J. H. VAN'T HOFF and ASSOCIATES. Leipzig: Akademische Verlagsgesellschaft m. b. H., 1912. Pp. xix+374, figs. 39, pls. 8.

The now classic work of van't Hoff and his associates on the crystallization of salts from sea water first appeared in the *Sitzungsberichte der Kgl. Preus. Akad. der Wissenschaften*, and later, in two volumes published by Vieweg u. Sohn. Additions to the earlier work appeared

in various periodicals, some of which are not available to many readers. The desirability of making the work in its entirety more accessible has led to the publication of the present volume, which contains little or nothing that has not been previously published, but brings under one cover work that has hitherto been scattered through the literature of chemistry.

The first part of the book is devoted to simple compounds possible in sea water, with their hydrates, and solubilities, with particular reference to their phase-rule relationships with water. These are studied through a range including all reasonable temperatures of natural evaporation of sea water. Then more complex relationships, involving the equilibria between various combinations of these salts, their hydrates, and double salts, are studied with a rigorous application of the phase rule.

The methods of work are carefully outlined and the results are shown in diagrams that have been models for subsequent phase-rule studies for the past decade.

This monograph is a fitting memorial to the great chemist whom it commemorates and stands pre-eminently as an investigation carefully, thoroughly, and completely carried out—a finished piece of work.

A. D. BROKAW

Contributions to Economic Geology, 1910. Pt. I. Metals and Non-Metals except Fuels. By C. W. HAYES and W. LINDGREN. U.S. Geol. Survey Bull. No. 470. Pp. 558; figs. 64; pls. 17. Washington, 1911.

A collection of short papers and preliminary reports by various authors on investigations carried out during 1910.

The following papers are included:

Gold and silver: Trinity Basin, Cal.; Carson camp, Colo.; Upper St. Joe River Basin, Idaho; Ground Moraine in northwestern Montana; Elkhorn Mountains, Mont.; Ramsay, Talapoosa, and White Horse districts, Nev.; and Pinos Altos, N.M.

Copper: Burro Mountains, N.M.; Ducktown, Tenn.

Lead and zinc: Bear River Range, Idaho and Utah; Metaline District, Wash.

Rare metals: Arsenic deposits at Brinton, Vt.

Iron and manganese: Montevallo-Columbiana region, Ala.

Structural materials—building stone: Shelby County, Ala.; Granites of Massachusetts. Clays: Calhan, El Paso County, Colo.; Murphysboro quadrangle, Illinois; clays from Texas. Gypsum: Eagle County, Colo. Phosphates: Idaho Phosphate Reserve; Melrose, Mont.; western Wyoming. Mineral paints: paint shales of Pennsylvania. Sulphur: deposits near Soda Springs, Idaho. Miscellaneous non-metallic products: asbestos deposits in the United States; dolomite near Montevallo, Shelby County, Ala.; Graphite near Dillon, Mont.; fluor spar near Deming; N.M.

A bibliography of Survey publications on the subjects treated is found at the end of each chapter.

A. D. B.

Contributions to Economic Geology, 1910. Pt. II. Mineral Fuels. By M. R. CAMPBELL. U.S. Geol. Survey Bull. No. 471. Pp. 663; figs. 15; pls. 62. Washington, 1912.

This bulletin is a collection of short papers by various authors on coal and oil fields investigated by the United States Geological Survey during 1910.

The reports cover the following regions, grouped by states:

Petroleum and natural gas.—Kentucky: Campton oil pool, Knox County. Alabama: Fayette gas field. Wyoming: Powder River oil field. Utah: San Juan oil field; Grand River. California: San Joaquin Valley.

Coal and lignite.—North Carolina: Dan River. North Dakota: Ft. Berthold Indian Reservation. Montana: Baker, Terry, Glendive, Sidney, Culberson, Milk River, Livingston, Trail Creek, and Electric fields. Wyoming: Little Powder River, Sussex, Lost Spring, and Wind River fields. Colorado: Gunnison Valley. New Mexico: Tigeras field. Utah: Deep Creek and Blacktail Mountain fields.

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A. D. B.

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